DOCUMENT RESUME

ED 190 885 CE 026 570

TITLE	Military Curricula for Vocational & Technical Education. Basic Electricity and Electronics Individualized Learning System. CANTRAC A-100-0010. Module Eight: Induction. Study Booklet.
INSTITUTION	Chief of Naval Education and Training Support, Pensacola, Fla.: Ohio State Univ., Columbus. National Center for Research in Vocational Education.
REPORT NO	NAVEDTRA-34258-8
PUB DATE	Mar 77
NOTE	129p.: For related documents see CE 026 560-593.
EDRS PRICE	MF01/PC06 Plus Postage.
DESCRIPTORS	*Electricity: *Electronics: Individualized Instruction: Learning Activities: Learning Modules: Postsecondary Education: Programed Instruction: *Technical Education
IDENTIFIERS	*Electric Power Generation: *Electromagnetic Theory: *Induction (Electronics): Military Curriculum Project

ABSTRACT

This individualized learning module on induction is one in a series of modules for a course in basic electricity and electronics. The course is one of a number of military-developed curriculum packages selected for adaptation to vocational instructional and curriculum development in a civilian setting. Four lessons are included in the module: (1) Electromagnetism, (2) Inductors and Flux Density, (3) Inducing Voltage, and (4) Inductance and Induction. Each lesson follows a typical format including a lesson overview, a list of study resources, the lesson content, a programmed instruction section, and a lesson summary. (Progress checks are provided for each lesson in a separate document, CE 026 562.) (LRA)

NAVEDTRA 34258-8

CHIEF OF NAVAL EDUCATION AND TRAINING

MARCH 1977

Military Curricula for Vocational & Technical Education

BASIC ELECTRICITY AND ELECTRONICS INDIVIDUALIZED LEARNING SYSTEM.

MODULE EIGHT. INDUCTION.

STUDY BOOKLET.

THE NATIONAL CENTER
FOR RESEARCH IN VOCATIONAL EDUCATION
THE OHIO STATE UNIVERSITY

MILITARY CURRICULUM MATERIALS

The military-developed curriculum materials in this course package were selected by the National Center for Research in Vocational Education Military Curriculum Project for dissemination to the six regional Curriculum Coordination Centers and other instructional materials agencies. The purpose of disseminating these courses was to make curriculum materials developed by the military more accessible to vocational educators in the civilian setting.

The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

Military Curriculum Materials Dissemination Is . . .

an activity to increase the accessibility of military-developed curriculum materials to vocational and technical educators.

This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

The National Center for Research in Vocational Education is the U.S. Office of Education's designated representative to acquire the materials and conduct the project activities.

Project Staff:

Wesley E. Budke, Ph.D., Director
National Center Clearinghouse

Shirley A. Chase, Ph.D.
Project Director

What Materials Are Available?

One hundred twenty courses on microfiche (thirteen in paper form) and descriptions of each have been provided to the vocational Curriculum Coordination Centers and other instructional materials agencies for dissemination.

Course materials include programmed instruction, curriculum outlines, instructor guides, student workbooks and technical manuals.

The 120 courses represent the following sixteen vocational subject areas:

Agriculture	Food Service
Aviation	Health
Building & Construction Trades	Heating & Air Conditioning
Clerical Occupations	Machine Shop
Communications	Management & Supervision
Drafting	Meteorology & Navigation
Electronics	Photography
Engine Mechanics	Public Service

The number of courses and the subject areas represented will expand as additional materials with application to vocational and technical education are identified and selected for dissemination.

How Can These Materials Be Obtained?

Contact the Curriculum Coordination Center in your region for information on obtaining materials (e.g., availability and cost). They will respond to your request directly or refer you to an instructional materials agency closer to you.

CURRICULUM COORDINATION CENTERS

EAST CENTRAL
Rebecca S. Douglass
Director
100 North First Street
Springfield, IL 62777
217/782-0759

NORTHWEST
William Daniels
Director
Building 17
Airdustrial Park
Olympia, WA 98504
206/753-0679

MIDWEST
Robert Patton
Director
1515 West Sixth Ave.
Stillwater, OK 74704
405/377-2000

SOUTHEAST
James F. Shill, Ph.D.
Director
Mississippi State University
Drawer DX
Mississippi State, MS 39762
601/325-2510

NORTHEAST
Joseph F. Kelly, Ph.D.
Director
225 West State Street
Trenton, NJ 08625
609/292-6562

WESTERN
Lawrence F. H. Zane, Ph.D.
Director
1776 University Ave.
Honolulu, HI 96822
808/948-7834

The National Center Mission Statement

The National Center for Research in Vocational Education's mission is to increase the ability of diverse agencies, institutions, and organizations to solve educational problems relating to individual career planning, preparation, and progression. The National Center fulfills its mission by:

- Generating knowledge through research
- Developing educational programs and products
- Evaluating individual program needs and outcomes
- Installing educational programs and products
- Operating information systems and services
- Conducting leadership development and training programs

FOR FURTHER INFORMATION ABOUT
Military Curriculum Materials
WRITE OR CALL
Program Information Office
The National Center for Research in Vocational Education
The Ohio State University
1960 Kenny Road, Columbus, Ohio 43210
Telephone: 614/486-3655 or Toll Free 800/848-4816 within the continental U.S. (except Ohio)

THE NATIONAL CENTER
FOR RESEARCH IN VOCATIONAL EDUCATION
The Ohio State University · 1960 Kenny Road · Columbus, Ohio 43210
Tel (614) 486-3655 Cable CTVOCEDOSU/Columbus, Ohio

Military Curriculum Materials for Vocational and Technical Education

Information and Field Services Division

The National Center for Research in Vocational Education

OVERVIEW

MODULE EIGHT

INDUCTION

In this module you will delve more deeply into electromagnetic induction, learning about its effects, and how it is used to advantage in electrical circuits. You will learn of the physical components, called inductors, designed to take advantage of the phenomenon of electromagnetic induction.

For you to more easily learn the above, this module has been divided into the following four lessons:

TURN TO THE FOLLOWING PAGE AND BEGIN LESSON I.

DON'T GET TURNED ON

PLAY IT COOL WITH ELECTRICITY

NAVPERS 94558-8a

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDULIZED LEARNING SYSTEM

M O D U L E E I G H T

L E S S O N I

Electromagnetism

Study Booklet

Bureau of Naval Personnel
January 1972

OVERVIEW
LESSON 1

Electromagnetism

In this lesson you will study and learn about the following:

- -reviewing your power supply
- -magnetic fields around a straight conductor
- -left-hand rule for conductors
- -magnetic field around a loop
- -magnetic field around a coil
- -lines of flux around a coil
- -left-hand rule for coils
- -applications of electromagnetism
- -the electric bell
- -the relay

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES

LESSON I

Electromagnetism

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative

Programmed Instruction

Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1b "Basic Electricity, Alternating Current."
Fundamentals of Electronics. Bureau of Naval Personnel.
Washington, D.C.: U.S. Government Printing Office, 1965.

AUDIO-VISUAL:

Sound/Slide Presentation - "Lenz's Law."

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON 1

Electromagnetism

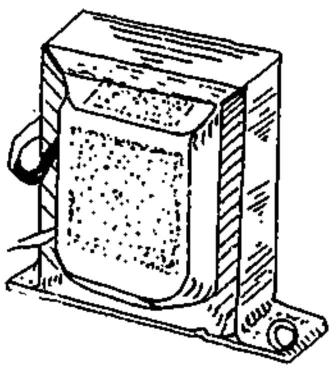
Reviewing Your Power Supply

Place the power supply you constructed at the beginning of this course in front of you. Let's briefly recap some of the things you have learned about the power supply:

1. It is a series-parallel circuit.
2. Alternating current is coming into the circuit from an outside source.
3. The purpose of the power supply is to convert AC into DC and provide the appropriate voltages for loads.
4. A lamp and four resistors of certain ohmic values are some of the components of the power supply.
5. The amount of resistance in the circui. limits the amount of current flow in the power supply.

There are several other items in your power supply, however, that you still cannot identify. In this lesson, you will begin to learn about one of these unfamiliar components, the inductor. It is a basic component and makes possible many of the electronic devices which people take for granted.

Look at your power supply and find the component that is connected between terminals T2 and T3. It looks like this:

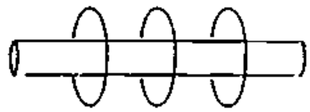


This is called an inductor, a choke, or a coil. On the inside of this inductor there is a coil of wire wrapped around an iron core. To understand what an inouctor does in the circuit, we need first to talk about electromagnetism.

Magnetic Fields Around a Straight Conductor

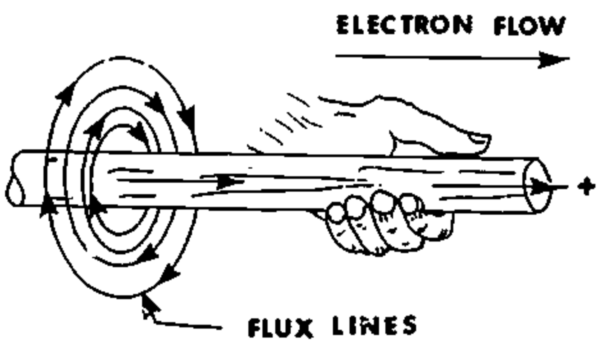
Any time current passes through a conductor, it creates a magnetic field around the conductor. In other words, when current begins to flow through a straight piece of wire, magnetic lines of flux originate at the center of the wire and spread out, passing through the insulation of the conductor and establishing a magnetic field around the wire. This wire then becomes a small magnet which we call an electromagnet.

These flux lines form a circular pattern around the conductor at right angles to the wire. The direction in which the flux lines circle the conductor is determined by the direction of current flow through the conductor.

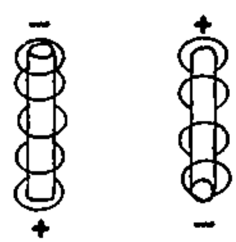


Left-hand Rule for Conductors

We can determine the direction of the flux lines by using the left-hand rule for conductors. The left-hand rule for conductors says that if you grasp the conductor in your left hand, with your thumb pointing in the direction in which electron current is flowing through the conductor, your fingers around the conductor will point in the direction that the flux lines are circling.

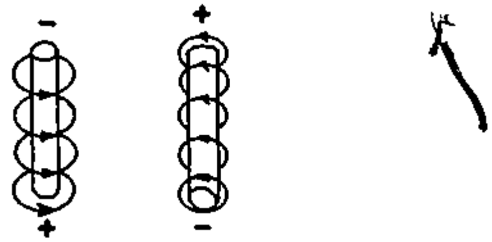


Look at this illustration. Recall that electron current flows through a conductor from negative to positive. The thumb points in the direction of current flow. The fingers then indicate the direction in which the magnetic lines circle the conductor.



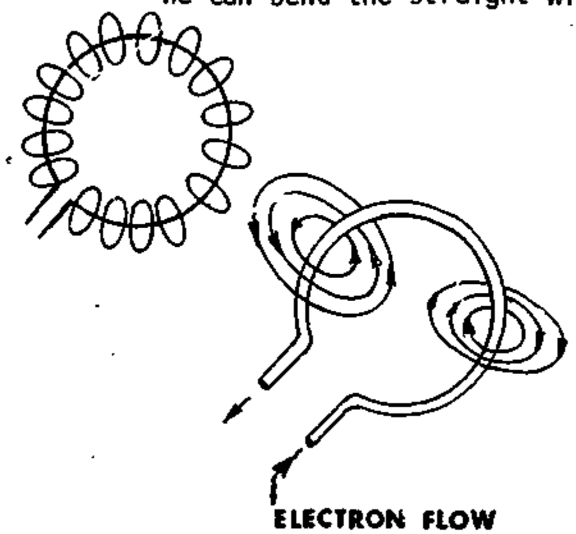
In these illustrations, by using the left-hand rule for conductors, determine the direction of the flux lines; draw arrows to indicate.

Answers:



Magnetic Field Around a Loop

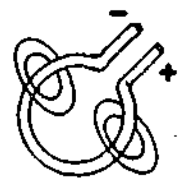
We said that a conductor with current passing through it is a small electromagnet. If we want to make the conductor a stronger magnet, we can bend the straight wire into a loop, such as the one below.



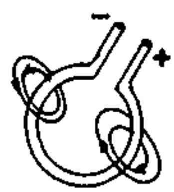
This brings the lines of flux closer together. Thus we have increased the flux density and we have a stronger magnet.

By using the left-hand rule for conductors, we can determine the direction in which the flux lines circle, as shown in the illustration by arrows.

In this illustration, determine the direction of the flux lines and draw arrows to indicate.



Check to see if you were correct:



Magnetic Field Around a Coil

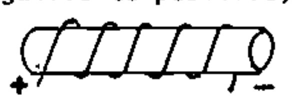
We said that we can produce a stronger electromagnet by bending a straight piece of conductor into a loop, and this increases the flux density by drawing the flux lines closer together.

To make an even stronger electromagnet we can wrap our straight conductor around and around into a coil like this: .

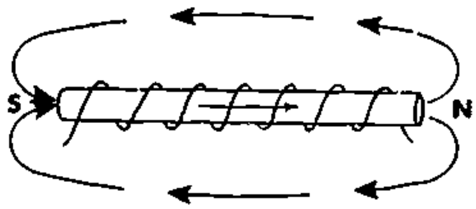
When we coil a piece of wire, we are creating many loops, so that flux lines from many of the loops interact, thus increasing flux density and increasing the strength of the magnet.

Lines of Flux Around a Coil

This illustrates an electromagnet that is a coil of conductor wrapped around a core. As current flows through the coiled conductor from negative to positive, the magnetic lines of force surrounding each loop extend themselves to provide a single magnetic field around the coil.



You are already familiar with flux lines that make these patterns around a magnet. Recall that the lines of flux leave the north end of the magnet, circle the magnet and enter the south end of the magnet. The lines of flux go through the core material from S to N.

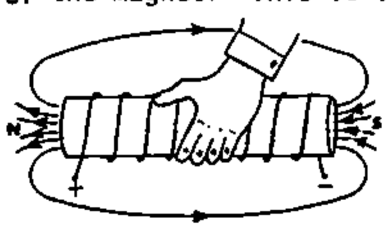


Left-Hand Rule for Coils

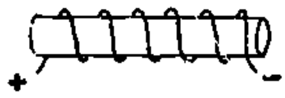
When you know the direction of current flow through a coil, you can determine the polarity of the magnet (which end is N and which is S) by using the left-hand rule for coils.

This will be especially meaningful to you in A School when polarity of an electromagnet is important to proper motor function.

The left-hand rule for coils states that if you wrap the fingers of your left hand around the coil so that the fingers point in the direction of current flow, the thumb will point to the North end of the magnet. This is illustrated here. Observe the fingers are circling under and in back of the coil because the current enters the conductor at the negative end of the wire, and then, in this case, goes up the back side of the coil and down the front side.



If, instead, the conductor were placed around the core as shown below, your fingers would wrap around the top of the coil and your thumb would be pointing this way ⟶, indicating the N pole.



Using the left-hand rule for coils, determine the polarity of these electromagnets. Write N and S at appropriate end of the magnets.

On coil (a), N is at the right end of the magnet.
On coil (b), N is at the left end of the magnet.

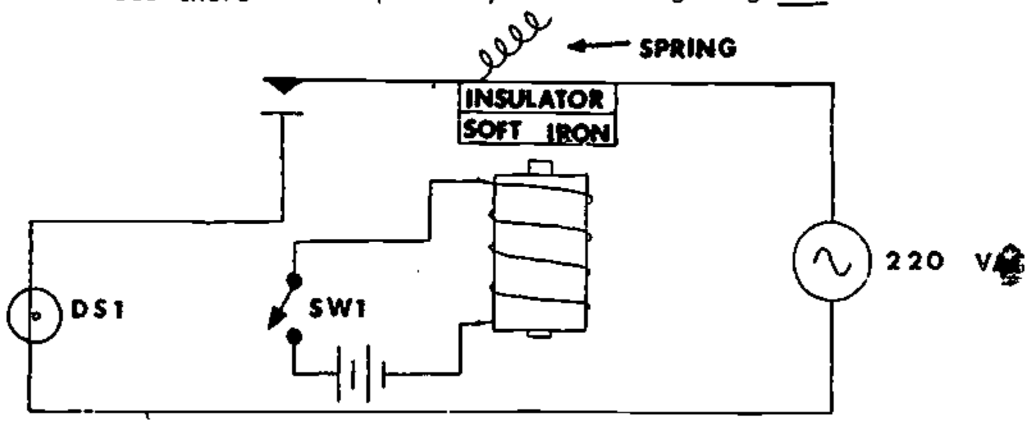
Some Applications of Electromagnetism

Electromagnetism is a concept basic to the understanding of induction, but it also explains how some common electrical devices work. We will briefly explain the role of electromagnets in two applications -- the relay, and the electric bell.

Relay

One application of an electromagnet is the relay. A relay is commonly used to control a high-voltage circuit without coming into physical contact with it.

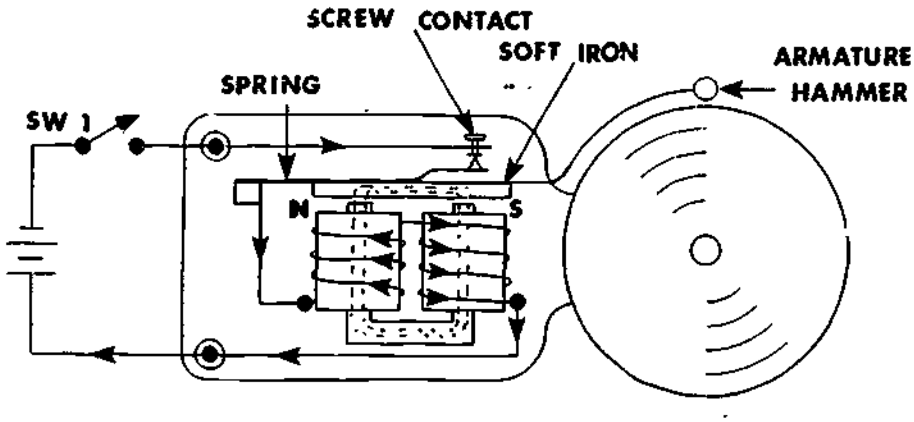
The following schematic illustrates an application of a relay. You can see there is a capability here of lighting DS1.



If switch 1 in the low-voltage circuit on Page 10 is closed, current flows from the battery through the coil. The magnetic lines of flux around the electromagnet draw the soft iron of the armature toward the coil. This pulls the arm down causing the high-voltage circuit to be energized, lighting the lamp DS1.

Electric Bell

The electric bell is one of the most common devices employing the electromagnet. A simple electric bell is shown below. Its operation is explained as follows:



1. When the switch (SW1) is closed, current flows from the negative terminal of the battery, through the contact points, the spring, the two coils, and back to the positive terminal of the battery.

Trace the path of current through the illustration by following the arrows.

---

2. The cores are magnetized, and the soft-iron armature is pulled down, thus causing the hammer to strike the bell.
3. At the instant the armature is pulled down, the contact is broken, and the electromagnet loses its magnetism. The spring pulls the armature up so that contact is re-established, and the operation is repeated. The speed with which the hammer is moved up and down depends on the stiffness of the spring and the weight of the moving parts.

As you go through A School, you will learn many applications for electromagnets. In the next lesson, you will concentrate on other applications of coils.

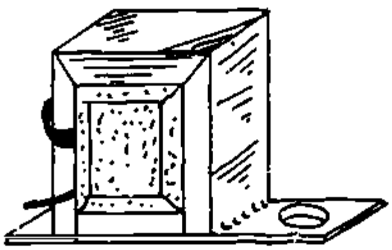
AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON I

Electromagnetism

TEST FRAMES ARE 12, 24, AND 35. AS BEFORE, GO FIRST TO FRAME 12 AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

There are several components in your power supply whose functions you don't know. The one we will study in this lesson is the inductor.

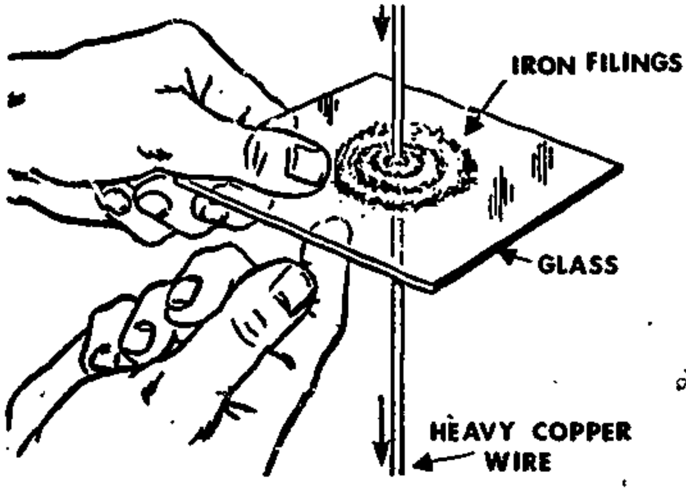


To understand its function in a circuit, we must know about electromagnetism.

1. Anytime current flows through a conductor, there is a magnetic field set up around the conductor. Therefore, electromagnetism is magnetism produced by ________.

(current)

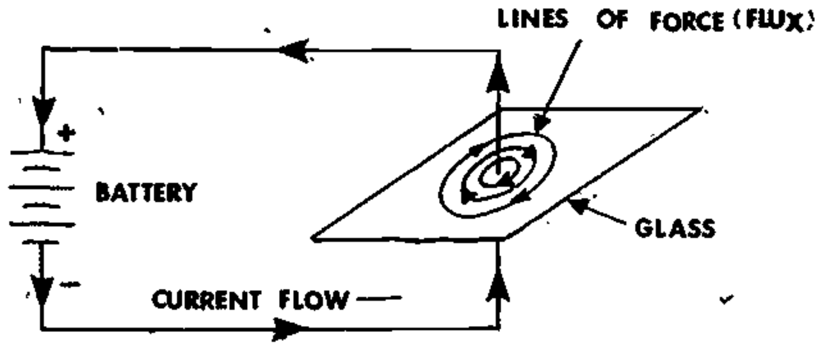
2. Below is a picture showing a demonstration of the relationship between current and its magnetic field.



The pattern formed is a series of ____________ around the wire.

(loops, rings, or circles)

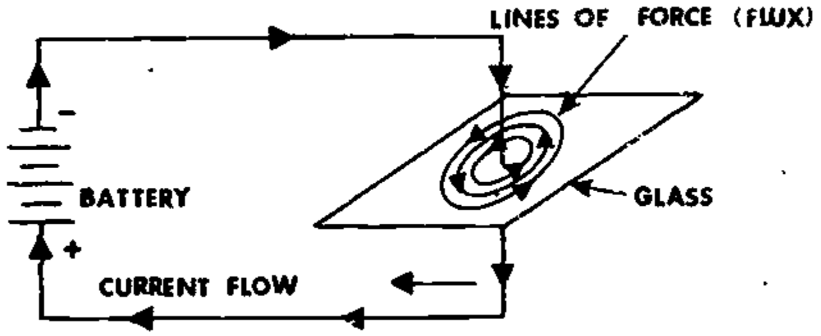
3.



If we were to construct a simple circuit, as shown above, a ________________ field would form around the conductor. (Note lines of force traveling in a clockwise direction.)

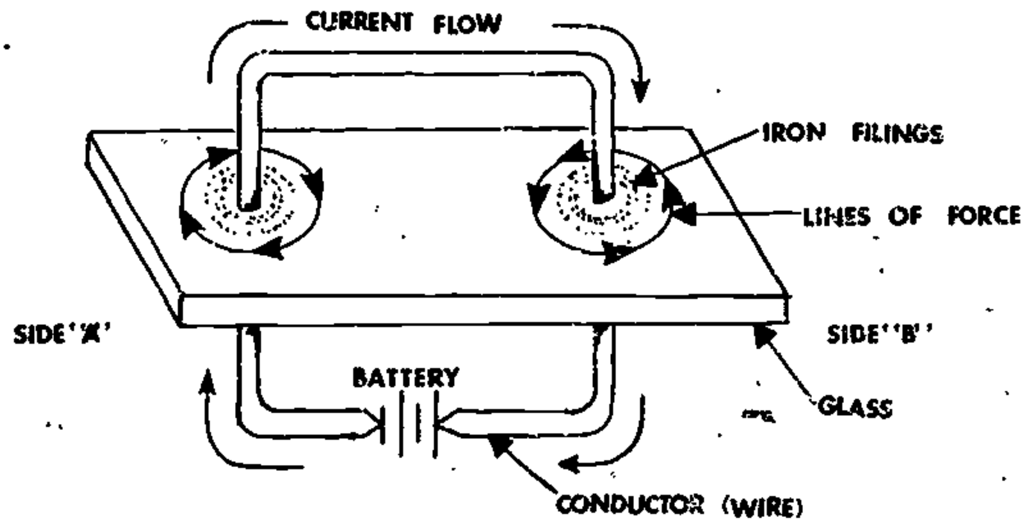
(magnetic)

4. However, if we were to reverse the current flow, as shown below, the lines of force would be in the __________ direction or counterclockwise.



(opposite)

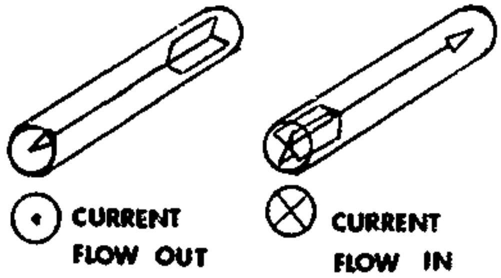
5.



In the illustration above, the lines of force on side A are traveling in a clockwise direction, but the lines of force on side B are traveling in a __________ direction.

(counterclockwise)

6. At this time, we need to introduce a couple of symbols used for current flow in future explanations.



(Go to next frame)

7. The magnetic field around a wire has no north or south pole; however, this field does have direction. Below are two diagrams showing the direction of this magnetic field.

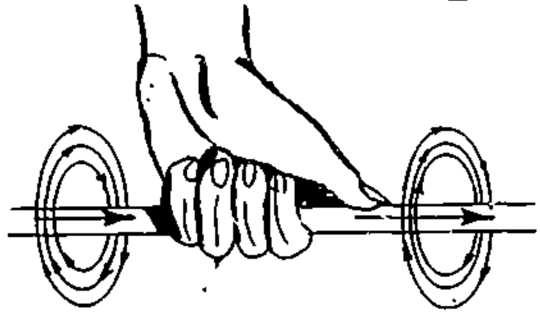
The diagram with the dot in the center represents current flowing ______________ the page.

(out of)

8. The left-hand rule for conductors is used to determine the direction of the magnetic lines of force around a conductor carrying a current, providing current direction is known. By the application of the left-hand rule, it is possible to determine the __________ of the __________ lines of __________.

(direction, magnetic, force/flux)

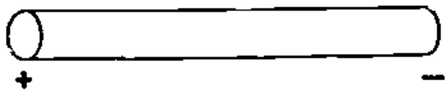
9. The left-hand rule for a conductor is as follows: POINT THE THUMB OF YOUR LEFT HAND IN THE DIRECTION OF CURRENT FLOW; YOUR FINGERS CURVE IN THE DIRECTION OF THE LINES OF FLUX.

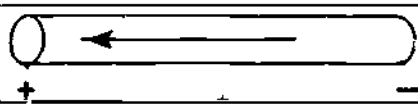


To determine the direction of lines of flux around a conductor, you use your ______ ________ hand.

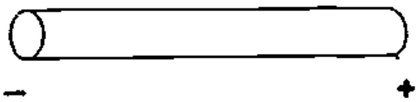
(left)

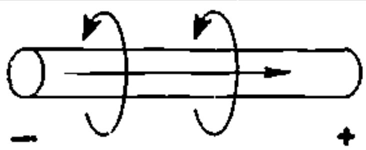
10. To indicate the direction of current flow in a conductor, arrows are generally used. However, in some cases it is necessary to use symbols: (+) or (-). Current always flows from negative (-) to positive (+). In the illustration below, indicate with an arrow the direction of current travel.





11. In the following sketch, mark the direction of current flow and lines of force with arrows.

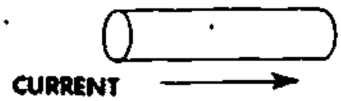




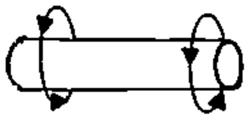
12. Now let's have a brief review of the material covered up to this point. Complete the following self-test.

a. Write the definition of electromagnetism. ______________________
____

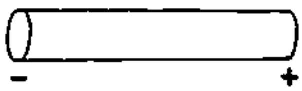
b. In the following sketch, indicate by arrows the direction of the lines of force.



c. In the following sketch, indicate by an arrow the direction of current flow.



d. In the following sketch, indicate by arrows the direction of current flow and lines of force.

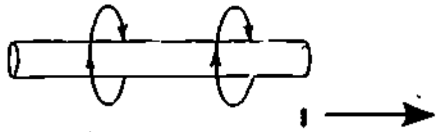


(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

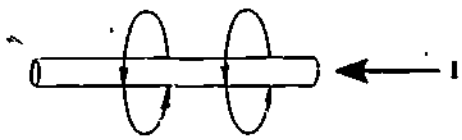
ANSWERS - TEST FRAME 12

a. Magnetism created by current flow through a conductor is electromagnetism. (See frame 1.)

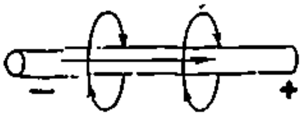
b.



c.

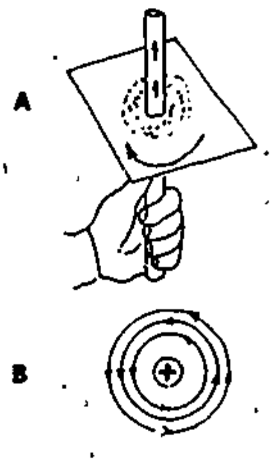


d.



IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 24. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 12 AGAIN.

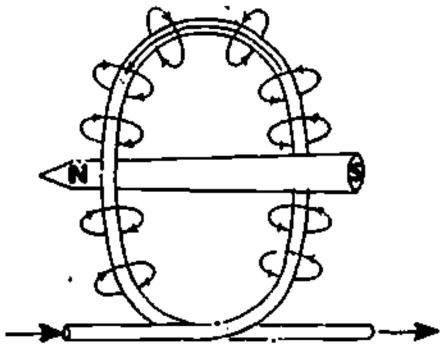
13.



The magnetic field around a straight conductor has little value. It has direction, but no north or south pole. It has force, but this force is relatively weak.

(Go to the next frame.)

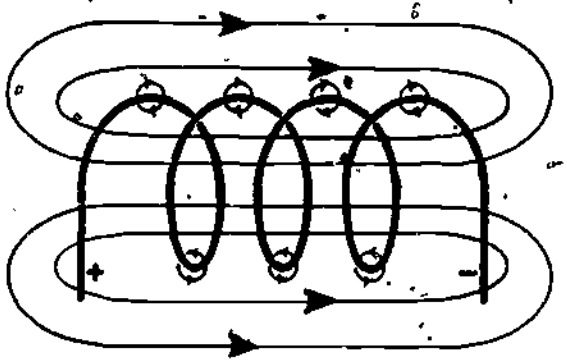
14. If a straight, current-carrying conductor is formed into a loop, north and south poles are created. This loop has all the characteristics of a magnet, but the field is still weak.



To create a north and south pole using a conductor, you form the conductor into a ________________.

(loop)

15. Now, by forming several loops of wire (which has current flowing through it), we make a stronger magnetic field. These loops form a <u>coil</u>. The area inside the coil is called the <u>core</u>. The core material is generally air or soft iron.



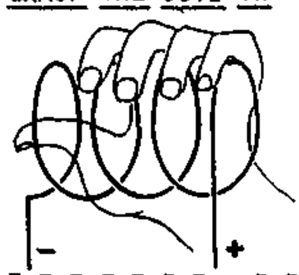
a. In order for the flux lines of each loop to add to the flux lines of the next loop, the loop currents must flow in the ____________ direction.

b. Several loops of wire formed into a spiral is called a ________________.

(a. same; b. coil)

27

16. To determine the north pole of any coil, we use the left-hand rule. The left-hand rule for coils is as follows: GRASP THE COIL IN YOUR LEFT HAND SO THAT YOUR FINGERS POINT IN THE DIRECTION OF CURRENT FLOW AROUND THE COIL; YOUR THUMB POINTS TO THE NORTH POLE. To determine the north pole of any coil, you use your ________ hand.

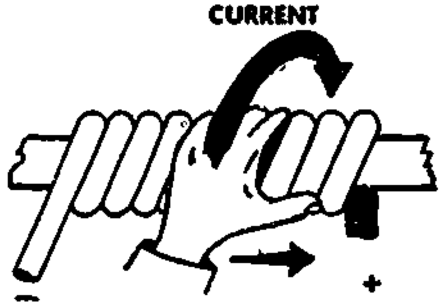


(left)

17. To determine the north and south poles of a coil, you must know the direction of ____________ ____________. This is the ______________-hand rule for a coil.

(current flow; left)

18. Label the south pole in the illustration below.

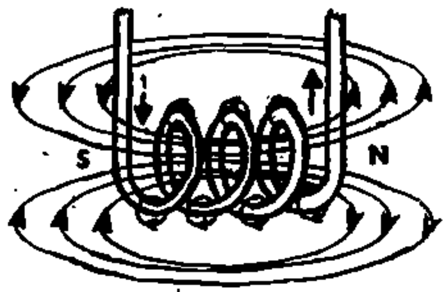


(S)

19. When using the left-hand rule for coils, your fingers point in the direction of current flow ____________________.

(through the coil)

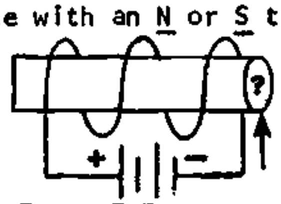
20.



By grasping the coil in your left hand so that your fingers point in the direction of current flow, your __________ points to the north pole.

(thumb)

21. In this diagram, the arrows indicate the direction of current flow in the coil. Indicate with an N or S the pole in question.



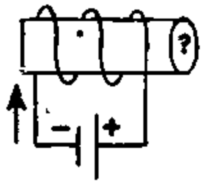
(S)

22. To find the N-S polarity of a coil, you must know (1) the end of the coil that current enters and (2) the direction in which the coil is wound. By knowing these two things, you are able to point your fingers in the direction of the __________ __________ through the windings of the coil.

With the fingers pointing in the direction of current flow around the coil, the thumb points to the __________ __________ of the coil.

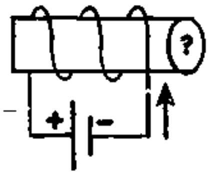
(current flow; north pole)

23. Select the correct magnetic polarity of the pole in question.



(S)

24. Is the pole marked with a question mark a North or South Pole?



(THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWER - TEST FRAME 24

North

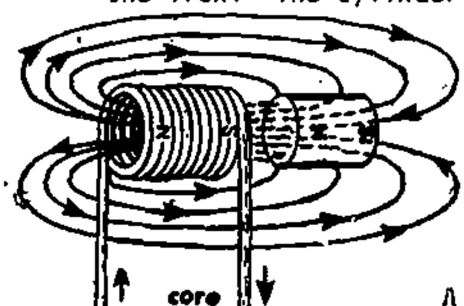
IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO ON TO TEST FRAME 35. OTHERWISE, GO BACK TO FRAME 13 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 24 AGAIN.

25. We have talked about the _______-hand rules for conductors and coils.

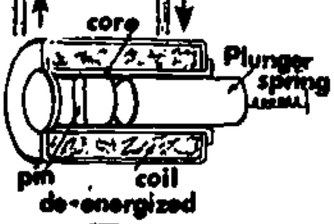
Now, let's discuss two types of coils often used in electrical circuits.

First, the solenoid.

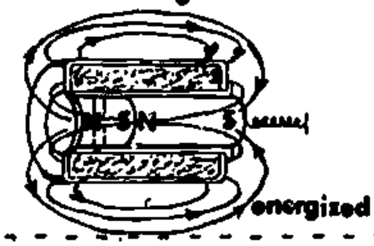
The solenoid is a coil of wire with a movable iron core. When an iron cylinder is placed near one end of an energized electromagnet (coil), the flux lines are concentrated through the iron. The cylinder is attracted by the magnet (see figure A) and is virtually sucked into the center of the coil. When a spring is attached to one end of this movable iron core, the core (plunger) is pulled out of the coil when it is de-energized (see figure B). We now have a mechanical movement that we can use. The fact that the movable iron core centers itself in an energized coil is known as solenoid action.



A



B



C

26. The solenoid generally has a _________ _________ core.

(movable iron)

27. If nothing stops its movement, the iron core moves to the _______________ of the energized coil.

(center)

28. A coil with a movable iron core is called a _____________.

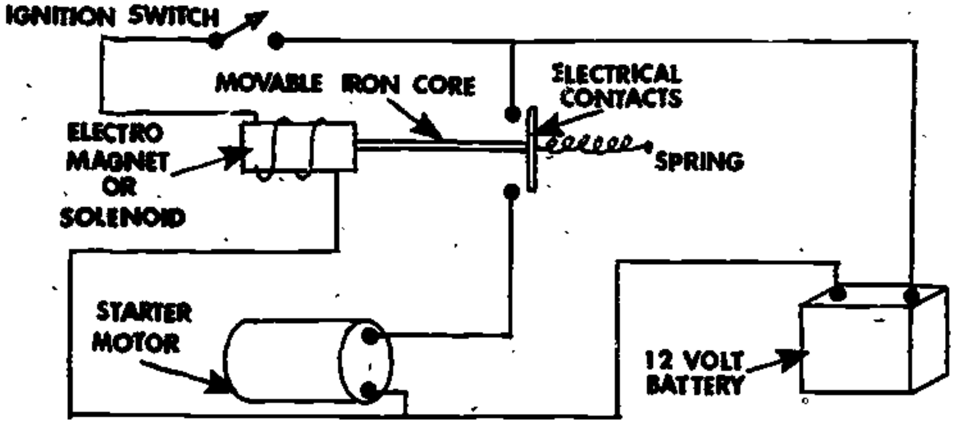
(solenoid)

29. A device used in electrical equipment to remotely control high-power circuits is the relay. The relay uses an electromagnet or solenoid in its operation. The electromagnet or solenoid in a relay is used to open and close electrical contacts without physical contact. The relay coil has its own low-power circuit, separated from the circuit it is controlling.

The starting solenoid in your automobile is an example of a relay at work. Let's look at a drawing of a typical auto starting circuit.

(Go to next frame.)

30.



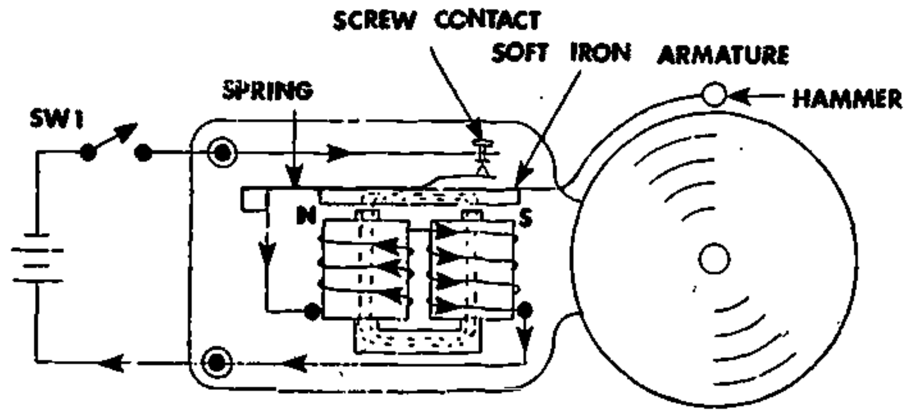
The high current contacts are connected in series with the starting motor. A separate circuit of small wire is routed through an on/off switch on the dash, and then to the solenoid near the starting motor. When the ignition switch is closed, the solenoid rgizes. The plunger is pulled into the coil, thus closing the contacts. This causes the starter motor to turn.

Using this solenoid relay, only small wire need be routed from the relay to the dash board. The heavy, high-current-carrying wire is kept as ________ as possible, and provides a method for energizing the high power circuit without physical contact.

(short)

NOTE: This is safer and minimizes the I^2R loss.

31. Instead of solenoids, smaller relays generally use a fixed core electromagnet in their operation. The door bell is an example of this.



(Go to next frame.)

---

32. Before we conclude this lesson, let's discuss a question often asked by students: Why do we use a relay instead of a regular switch?

One major use of the relay is the remote control of electrical and electronic circuits. Circuits may be energized from one or more stations simply by closing a switch. This means a relay can eliminate the necessity of running heavy power cables to various control points.

So, the first use of the relay is the ________ ________ of electrical circuits.

(remote control)

33. Another major use of the relay is the removal of safety hazards. High-voltage equipment can be turned on or off by a relay. A separate low-voltage supply and switch are used by the operator to energize the relay.

So, the second main use of the relay is the removal of __________ __________ to the operator from high-voltage equipment.

(safety hazards)

34. Turning on the ship's radar, for example, utilizes both uses of the relay. The operator has __________ __________ of the radar's circuits and he is removed from the safety hazards of the radar's __________ __________.

(remote control, electrical circuits)

35. State in your own words, the primary purpose or purposes for using a relay.

____

____

____

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS — TEST FRAME 35

1. Remote control of circuits without the necessity of running great lengths of high-current wiring.

2. Decrease safety hazards involved in physically controlling high-power circuits.

(Or, words to this effect)

IF ANY OF YOUR ANSWERS IS INCORRECT, GO BACK TO FRAME 25 AND TAKE THE PROGRAMMED SEQUENCE.

IF YOUR ANSWERS ARE CORRECT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO ON TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY
LESSON I

Electromagnetism

An important electronic component is the inductor, or choke; it is a coil which is often wrapped around an iron core. To understand the inductor, we must first review the principles of electromagnetism.

1. A conductor carrying current is encompassed by a magnetic field having direction, but no north or south pole. As always, the lines of the magnetic field form closed loops.

2. By using your left hand, the direction of this field can be determined. Similarly, knowing the field's direction, the direction of current flow can be determined. If your left thumb points in the direction of the electron current flow, the curling left fingers show the magnetic field direction.

3. Forming the conductor into a loop creates a stronger magnetic field and a definite north and south pole.

4. Using the left hand, you can again determine the north pole and the direction of current flow in the coil. If your fingers circle in the direction of electron current flow, your thumb indicates the north pole and its energizing magnetic field.

Review in the narrative some of the applications of electromagnetism such as the electric bell and relay circuits.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

NAVPERS 94558-8a

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE EIGHT
LESSON II

Inductors and Flux Density

Study Booklet

Bureau of Naval Personnel
January 1972

OVERVIEW

LESSON II

Inductors and Flux Density

In this lesson you will study and learn about the following:

-iron-core inductors
-air-core inductors
-factors that affect flux density

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES

LESSON 11

Inductors and Flux Density

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative

Programmed Instruction

Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1b "Basic Electricity, Alternating Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

NAVPERS 93400A-1a "Basic Electricity, Direct Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

5

NARRATIVE
LESSON 11

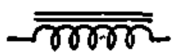
Inductors and Flux Density

In this lesson we will learn about two basic kinds of inductors and the factors that determine the capability of a coil to perform its function.

Iron-Core Inductors

Inductors are classified according to core type. The core is the center of the inductor just as the core of an apple is the center of an apple. The inductor is made by wrapping a coil of wire (conductor) around a core. The core material is normally one of two basic types: soft iron or air. The inductor in your power supply has an iron core.

An iron-core inductor is schematically represented by a coil with lines across the top of it to indicate the presence of an iron core:

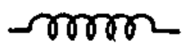


Air-Core Inductors

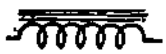
The air-core inductor may be nothing more than a coil of conductor, but it is usually a coil formed around a hollow shape of some non-magnetic material such as cardboard. This material serves no purpose other than to hold the shape of the coil.

This is an illustration of an air-core inductor:

The schematic symbol for an air-core inductor is a coil without bars across the top:



Draw the correct schematic symbol for the inductor in your power supply.



The type of core material used in an inductor is important because it affects the strength of the magnetic field around the coil. We are talking now about flux density which, you recall, refers to the number of flux lines in a given area. The greater the flux density, the stronger the magnetic field.

Factors That Affect Flux Density

We will first discuss four factors that directly affect flux density. (A fifth factor affects the flux density inversely.)

1. Permeability refers to the ease with which magnetic flux lines pass through a material. Flux lines move more easily through materials with high permeability. Flux lines pass more easily through iron than they do through air; therefore, an iron-core has much higher permeability than an air-core.

   The term that means the opposite of permeability is reluctance. The reluctance of a material is the opposition which the material offers to the passing of flux lines through it. A high-reluctance material, therefore, has low permeability. Flux lines have more difficulty passing through air than through almost any other material, so we can say that air has high reluctance and low permeability. On the other hand, iron has high permeability and low reluctance.

Match:

____ 1. has greater permeability a. 

____ 2. has greater reluctance b. 

Your answers should be:

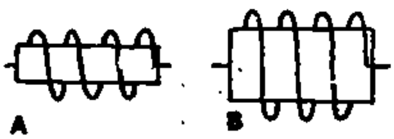
1. b
2. a

The higher the permeability of the core, the greater the flux density.

---

2. The number of turns of conductor in the coil affects flux density in the core. When there are more turns closer together, the flux density is greater.

3. The Cross-Sectional Area of the Core also affects flux density. If the diameter or cross-sectional area of the core (for a given coil) is increased, more flux lines can pass through the material. In figures A and B we have two cores of equal length, of identical material, and with the same number of turns of conductor. The only



difference between these two coils is that the core of coil B has a larger cross-sectional area. Flux density will be greater around coil B than around coil A.

4. The Amount of Current through the coil affects flux density. The greater the amount of current, the greater the flux density.

If you increase any of the four factors we have mentioned -- permeability of the core, the number of turns of the conductor, the cross-sectional area of the core, or the amount of current through the coil -- flux density increases. If any of these factors decreases, flux density decreases.

One other factor affects flux density, and that is the length of the core. Just as a long piece of wire offers more resistance to current flow than a short piece, a long core offers more reluctance to the passing flux lines through the core. So if you insert a longer core in a coil, flux density decreases.

If you shorten the core, keeping all turns around it, will flux density increase or decrease?

Answer: It will increase.

Summary. These five factors affect flux density and the capability of an inductor:

1. Permeability of core 2. Number of turns of conductor 3. Cross-sectional area of core 4. Amount of current through the coil	Increasing these increases flux density.
5. Length of core	Increasing length decreases flux density.

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON II

Inductors and Flux Density

TEST FRAMES ARE 10 AND 17. AS BEFORE, GO FIRST TO TEST FRAME 10 AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

In this lesson you will learn about factors that determine the characteristics of inductors.

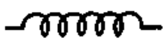
1. There are two types of inductors; they are distinguished by their type of core.

   How is the type of inductor determined? __________

- -

(core material)

---

2. The first one to be discussed is the air-core inductor. It is shown schematically as:  OR 

   And it appears something like this: 

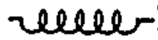
   What type material is used for the core of the inductor shown below?

- -

(air)

---

3. An air-core inductor () is normally found in circuits operating at high frequencies - radio, TV, etc.

   For radio-frequency application an air-core inductor __________ normally be used. would/would not

- -

(would)

---

4. The second type inductor is the iron-core inductor. It is schematically shown as  . The parallel lines denote the iron core. The inductor in your power supply is of this type, and is connected between terminals T2 and T3.

Match the drawing to the description.

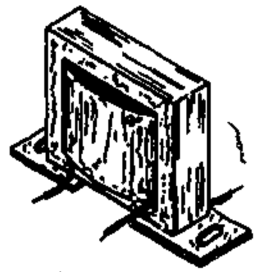
____ 1. air-core inductor

____ 2. iron-core inductor

____ 3. schematic drawing of iron core

____ 4. schematic drawing of air core

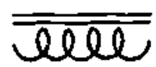
A



B

C

D



(1. c; 2. a; 3. d; 4. b)

5. The purpose of the iron core is to concentrate the magnetic flux lines, thus strengthening the flux field.

The iron-core inductor has a stronger ______________ than an air-core due to the type core material it has.

(magnetic field)

6. The ease with which a material passes lines of flux is called permeability. Air is the reference material with a permeability of 1.

An inductor with an __________ core is used as a reference and has a permeability of 1.

(air)

7. Soft iron passes flux lines more readily than air; it has a much higher permeability than air. Different types of iron have different degrees of permeability.

Which of the following core materials would have the strongest magnetic field for a given coil?

____ a. soft iron
____ b. air

(a) soft iron

8. Reluctance is the reverse of permeability and is a measure of the opposition a material offers to flux lines.

Soft iron has a high permeability and a ________ reluctance.

(low)

9. Reluctance is comparable to resistance. Both are a form of opposition.

Air offers maximum opposition to flux lines. Air is said to have a high ____________.

(reluctance)

10. Match the drawings to the statements.

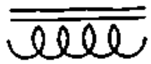
____ 1. has greater permeability

____ 2. has greater reluctance

____ 3. has less permeability

____ 4. has less reluctance

a. 

b. 

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 10

1. b
2. a
3. a
4. b

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 17. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 10 AGAIN.

11. Flux density is a measure of flux lines per unit area. Magnetic field strength is directly proportional to flux density.

    An iron-core inductor will have a __________ flux density and a stronger magnetic field than an air-core.

(greater)

12. Permeability, flux density, and magnetic field strength are related. A change in the permeability of the core material will cause a directly proportional change in flux density, thus causing a directly proportional change to the magnetic field strength.

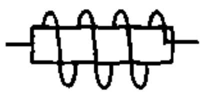
    If an increase in flux density increases the magnetic field, increasing permeability will ____________ the magnetic field.

(increase)

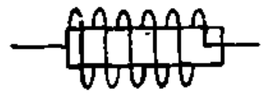
13. If the number of turns of wire on a coil are increased, the flux density of the coil will increase.

Which of the coils drawn below will have the greatest flux density?

____ A



____ B



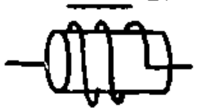
- -

(b)

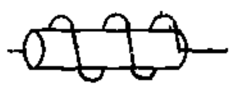
14. Another factor pertaining to flux density is the cross-sectional area of the core material. The greater the cross-sectional area of the core material for a given coil, the lower the reluctance and the more lines of flux per unit area.

Which of the drawings below will have the greatest flux density?

____ a.



____ b.



- -

(a)

15. The last of the four major factors affecting flux density is current flow. The higher the current flow in a coil the greater the number of individual lines of flux around each turn of the conductor, so the greater the total flux density.

List the four factors that have a direct effect on the flux density of a coil. (Any order.)

a. ______________________________
b. ______________________________
c. ______________________________
d. ______________________________

- -

(number of turns of the coil); permeability of the core; cross-section of the core; amount of current flow in the coil)

16. If the cross-sectional area of the core is increased, flux density increases; however, if the length of the core is increased, flux density decreases.

    Flux density is ________________ proportional to core length.
    directly/inversely

(inversely)

17. List the five factors that affect flux density in an inductor.

    Directly Proportional

    a. ____________________

    b. ____________________

    c. ____________________

    d. ____________________

    Inversely Proportional

    e. ____________________

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 17

Directly Proportional: (may be in any order)

a. permeability of core

b. number of turns

c. cross-section of core

d. current flow through the coil

Inversely Proportional:

e. length of core

- -

IF ANY OF YOUR ANSWERS IS INCORRECT, GO BACK TO FRAME 11 AND TAKE THE PROGRAMMED SEQUENCE.

IF YOUR ANSWERS ARE CORRECT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO ON TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY
LESSON II

Inductors and Flux Density

We have seen in Lesson I that the inductor or coil produces a magnetic field via electromagnetism. Since we already have characterized a magnetic field by the important variable characteristic of flux density, we should investigate the major factors of an inductor which influence the flux density. There are five:

1. Permeability of the core material is the ease with which the magnetic flux passes through any material. Flux lines pass quite readily through iron, compared to air. Therefore, an iron core has a much greater permeability than an air-core inductor. (The opposite of permeability is reluctance which is a sort of magnetic resistance. A high-reluctance material has low permeability.)

2. The number of turns of the conductor in the coil has already been seen to directly affect the flux density in the core. As more turns are added to a coil the flux density increases.

3. The cross-sectional area of the core affects the flux density. If the diameter or cross-sectional area of the core (for a given coil) is increased, more flux can pass through the material.

4. The amount of current through the coil directly affects flux density. The greater the amount of current, the greater the flux density.

5. The length of the core affects flux density. Just as a long piece of wire offers more resistance to current flow than a short piece, a long core offers more reluctance to the passing of flux lines through the core than a short one. Therefore, this is an inverse factor. If we shorten the core, keeping the same number of turns around it, the flux density increases.

Keep in mind, as always, the amount of flux density determines the magnetic field strength.

There are two commonly used kinds of inductors: the air-core and the iron-core. Other types of inductors will be covered in detail later in the course.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

NAVPERS 94558-8a

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE EIGHT
LESSON III

Inducing Voltage

Study Booklet

Bureau of Naval Personnel
January 1972

OVERVIEW
LESSON III

Inducing Voltage

In this lesson you will study and learn about the following:

- -inducing voltage in a conductor
- -relative motion within a conductor
- -inducing an EMF
- -choking current flow
- -sustaining current
- -inducing a voltage in a second circuit
- -flux lines in induced circuit
- -Lenz's Law
- -change is vital to induction
- -use of AC sources

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON III

Inducing Voltage

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative
Programmed Instruction
Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1a "Basic Electricity, Direct Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

NAVPERS 93400A-1b "Basic Electricity, Alternating Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

AUDIO/VISUAL:

Sound/Slide Presentation: "Lenz's Law"

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON III

Inducing Voltage

In this lesson we will review the factors affecting the generation of an EMF and investigate the effect of this within a circuit.

Reviewing Generation of EMF

Recall from Module Two (Voltage), Lesson III (Electromagnetic Induction) that three factors are required to induce an EMF into a conductor. These are:

1. a magnetic field.
2. a conductor.
3. relative motion between the conductor and the field so that the flux lines are cut by the conductor. Remember, it doesn't matter which moves, the field or the conductor, so long as the relative motion exists.

With these three factors present, voltage is induced into the conductor.

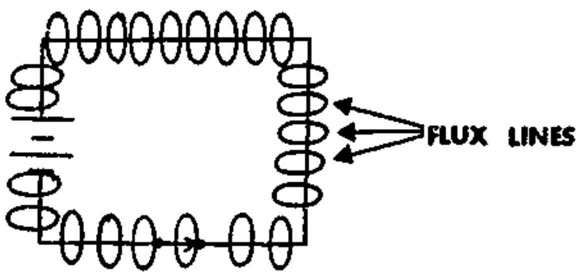
We also learned that the amount (magnitude) of the voltage induced depends upon the rate of speed with which the magnetic lines of flux are cut. The greater the rate of speed, the more EMF induced.

This is stated in Faraday's Law as: The EMF induced or generated in a conductor is in direct proportion to the rate at which the conductor cuts the magnetic lines of flux.

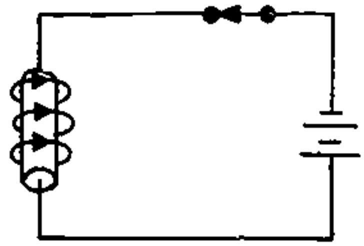
Inducing Voltage in a Conductor

You learned in the first lesson of this module that when current passes through a conductor, magnetic lines of flux build up around the conductor.

We can assume, then, that when the current flows in the circuit illustrated below, a magnetic field is created around the conductor.



Let's enlarge a section of the conductor and take a look at what is happening. We see the circuit with an enlarged section of conductor with flux lines around it.



Recalling that three factors are necessary to induce a voltage - a magnetic field, a conductor, and relative motion - we know that we have already satisfied two of these conditions.

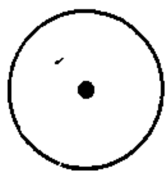
Which of the three factors is missing? ____________

If you said <u>relative motion between the field and the conductor</u>, you are correct. Although it may not be obvious, relative motion is often present in this situation. Let's see how.

Relative Motion Within a Conductor

With the switch open, there is no current flow in the circuit and therefore no magnetic field around the conductor. Let's close the switch. What happens? (1) Current starts to flow. (2) The magnetic field is created around the conductor.

In this illustration, we are looking at the enlarged section of a conductor from the end. The dot in the center indicates the current is flowing toward us.



The lines of flux will build from the center of the conductor as the current begins to flow.

If we look at the conductor in sections now, we can see that there is relative motion between the field and the conductor.

As the field builds from the center outward, the conductor seems to move in the opposite direction, as indicated by the arrow for the right half of the conductor.

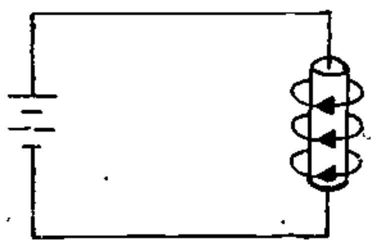
The left half appears to travel in the opposite direction in relation to the movement of the field. Any section of the conductor can be seen in the same way. It appears to move in the direction opposite to that of the field.

This, then, fulfills the third requirement for inducing a voltage, relative motion.

Inducing an EMF

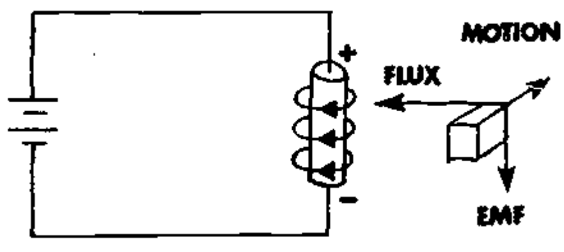
Since we have the three factors necessary for inducing a voltage, we can assume that a voltage is being induced in a conductor which begins to carry a current.

By the left-hand rule for generators, determine the polarity of the induced voltage.

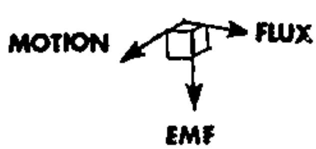


Recall: Thumb indicates direction of conductor motion; first finger indicates direction of flux lines; second finger indicates negative end of induced EMF.

You should have determined polarity of induced EMF as shown:



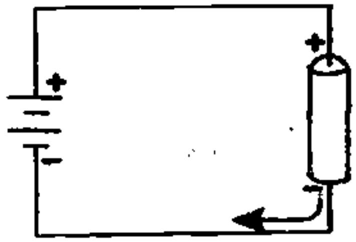
Note that the section of conductor you look at makes no difference in the polarity of the induced EMF. Suppose you look at the back side of the conductor. You will have this:



The negative end still is the bottom.

Choking Current Flow

Remember we have current flow in our circuit from the negative terminal of the source.



The induced EMF is attempting to cause current flow in the opposite direction, as shown by the arrow. This is counter to the actual flow of current caused by the source, so we call the induced EMF a counter EMF or CEMF.

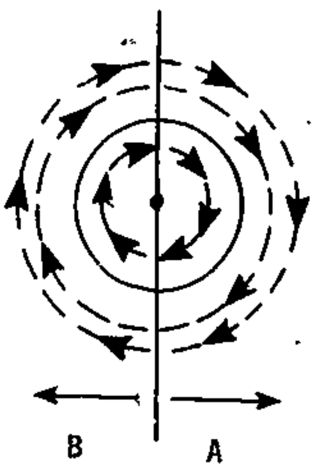
The CEMF obviously opposes the source and attempts to hold back, or choke, the current from the source. The CEMF is almost equal to the source voltage and results in the current's being reduced briefly. Think about this: Why would conservation of energy be violated if the induced EMF resulted in more current flow?

When the circuit current reaches its maximum steady value, will there be a CEMF in the conductor? ______________

No! We lose the requirement of relative motion because the field is in a fixed position around the conductor.

Sustaining Current

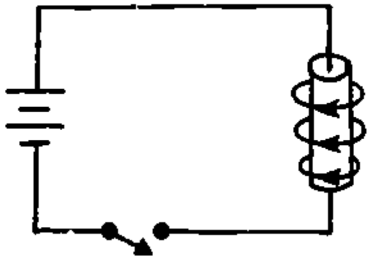
Since current has been flowing for a while, let's see what happens when we open the switch. (1) Current stops. (2) The magnetic field collapses.



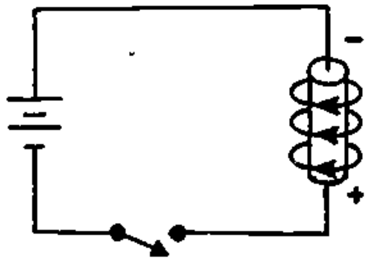
Now with a field collapsing, it is moving in toward the center of the conductor, once again causing the conductor to appear to move in the opposite direction. Half A appears to move to the right and half B to the left.

Again, we have relative motion and again we have an induced EMF.

By applying the left-hand rule for generators, determine the polarity of the induced EMF. (The field is collapsing.)



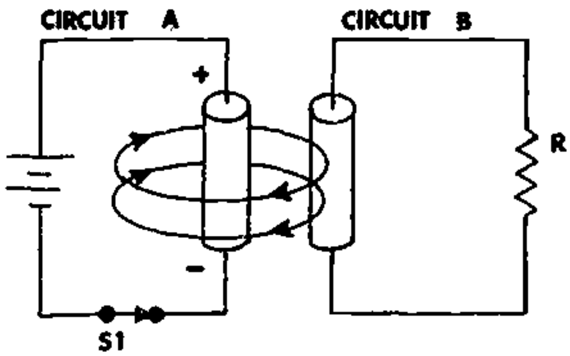
Once again, it doesn't matter which segment of the conductor we are considering; the induced EMF will be as indicated by the (+) and (-) signs.



Now, instead of opposing the source and moving electrons in the opposite direction, the induced EMF is attempting to <u>keep</u> the current flowing in the circuit. Although continued current flow is <u>not</u> possible in an open circuit, the EMF will push electrons in that direction until the field fully collapses.

<u>Inducing a Voltage in a Second Circuit</u>

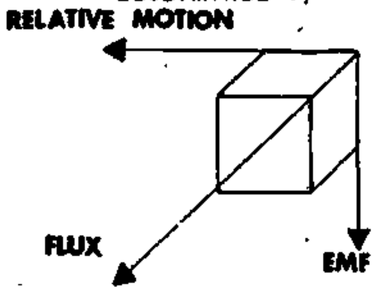
If we take the original circuit with the enlarged section of conductor and place close to it another circuit with an enlarged section of conductor (but without a source) and close switch <u>SW1</u>, we have something like this:



61

Now the magnetic lines of flux caused by the current flowing in Circuit A cut the conductor of Circuit B. Once again, the enlarged section of conductor in Circuit B appears to move to the left, and we have all three requirements for inducing a voltage: (1) magnetic field, (2) conductor, and (3) relative motion.

We have a voltage induced in Circuit B, whose polarity can be determined by the left-hand rule for generators.



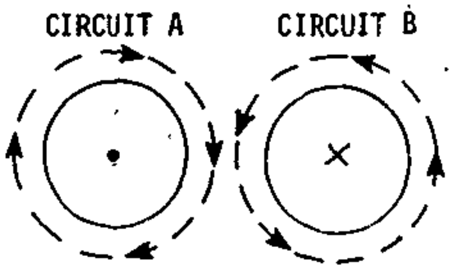
Flux Lines in Induced Circuit

The induced voltage acts as a source; thus, the current in Circuit B flows down from the enlarged conductor.

Since we have established that current will flow in Circuit B, will there be any magnetic flux lines around the conductor of Circuit B? ________

Yes! Any current-carrying conductor has magnetic lines of flux around it and perpendicular (at right angles) to it.

Let's again turn our enlarged conductor sections on end and take a look:



(The X in Circuit B indicates current is flowing away from us.)

Now, remembering that the current in Circuit B is caused by the field around Circuit A, consider the effect of the field around Circuit B. By the left-hand rule we can determine that the field around Circuit B will induce a voltage in Circuit B which will attempt to cause current to flow in the opposite direction, thus reducing current and the effect of the field around Circuit A.

Lenz's Law

This effect has been stated in Lenz's Law as: <u>The direction of an induced EMF is such that it tends to set up a current flow</u>

whose magnetic field always opposes a change in the field caused by the original current.

This rule is used to explain what happens in transformer action which we will cover more thoroughly in Module Ten.

What will be the direction of current flow in Circuit B when SW1 is opened after current has reached a maximum steady value? ____________________

Naturally, it is going to reverse; all conditions are the same except the direction of relative motion.

Change is Vital to Induction

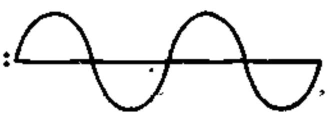
Notice that Circuit A has a DC source - a battery. The amount of current in the circuit will be determined by the amount of resistance in the conductor and the internal resistance.

In this circuit, current will have a constant value except for the instant the circuit is energized and the instant it is de-energized. Thus, the only time a magnetic field will be moving, so that relative motion exists between the field and the conductor, will be when the circuit is energized and de-energized.

We can see, then, that there must be a change in current flow to have a moving magnetic field, and without a moving field, (no relative motion) no induced EMF.

AC Sources

We know that AC current fluctuates constantly like this:



If we replaced the battery with an AC source, we would have a continuously changing current, thus continuously inducing an EMF. Any change in current will cause an EMF to be induced.

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

PROGRAMMED INSTRUCTION
LESSON III

Inducing Voltage

TEST FRAMES ARE 13, 18, 20, AND 28. AS BEFORE, GO FIRST TO TEST FRAME 13 AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

1. Recall from Module Two, that there are three factors required to generate an EMF by magnetic induction.

   They are: 1.

   2.

   3.

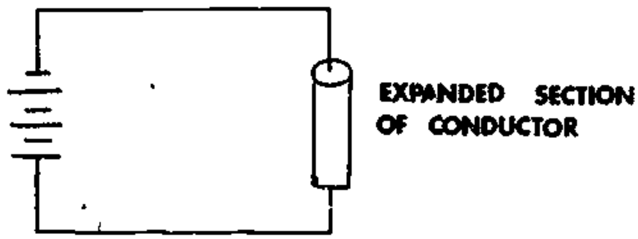
(1. conductor; 2. magnetic field; 3. relative motion between the conductor and field in such a manner that the conductor cuts the lines of flux)

2. Let's see how a voltage may be induced into a current-carrying conductor.

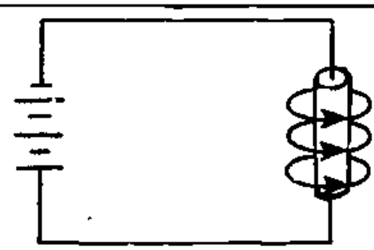
   Recall that current flowing through a conductor sets up a ________ ______________ around the conductor and at right angles to it.

(magnetic field)

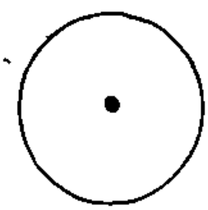
3. Use arrows to show the direction of the magnetic field around the expanded section of wire. (Hint: Remember the left-hand rule for conductors.)



- -

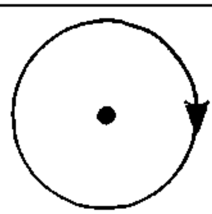


4. The magnetic field around a conductor originates at the <u>center</u> of the conductor and passes through the conductor as it expands outward.

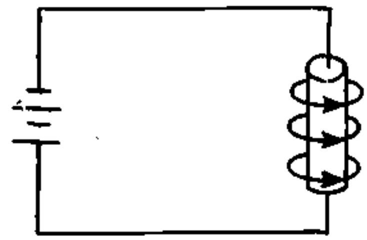


Here we see the end of a conductor with current flowing through it. The dot in the center indicates the current is flowing toward us (out of the paper.) Indicate by arrows the direction of lines of flux around the conductor.

- -



5. As the circuit below is energized, are the flux lines expanding or collapsing?



(expanding)

6. Since the field is expanding outward from the center, you can say the conductor's motion relative to the magnetic field is

______
outward/inward

(inward)

7. Due to the field's expanding through the conductor, a motion is established between the conductor and the field.

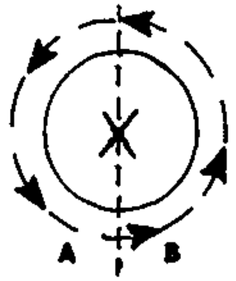
Relative motion exists in a current-carrying conductor because of the:

____ a. physical nature of the conductor.
____ b. collapsing of the conductor.
____ c. expanding of the field.

(c) expanding of the field

66

8. To determine the direction of the induced EMF, let's look at a small section of the conductor. (Note: The X in the center of the conductor represents current flow into the page.)

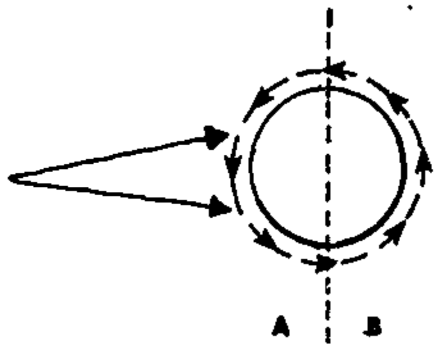


Assume the magnetic flux is expanding and apply the left-hand rule for generators to determine the polarity of the EMF induced into side B of the conductor. State the polarity of the induced voltage on the end of the conductor toward you. ______________.

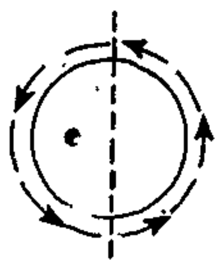
Recall: thumb —— direction of motion; first finger —— direction of flux; second finger —— direction of induced EMF

(negative)

9. Now, look at side A of the same conductor.

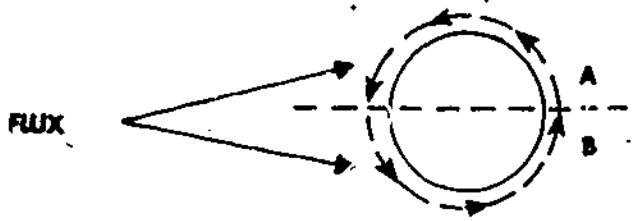


Indicate the direction of induced electron movement in side A. (X into the page, . out of the page)

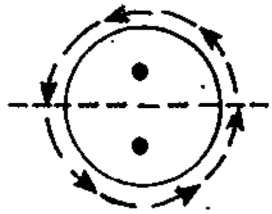


67

10. Let's split the same conductor a different way.

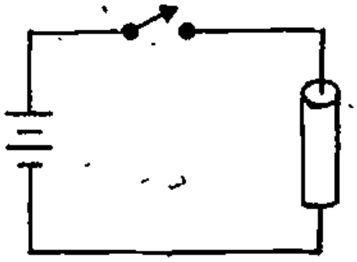


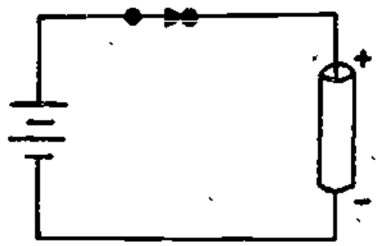
Indicate the direction of electron flow for each half.



11. You can see that no matter which point around the conductor you check, the induced EMF is always in the same direction.

Label the expanded conductor in the schematic below to indicate the polarity of the induced EMF the instant the switch is closed.





68

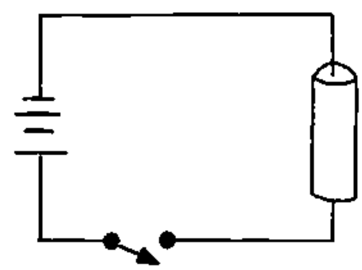
12. You can also see that the induced EMF is attempting to cause current to flow in the direction opposite to the direction of current flow caused by the source.

    We call the induced EMF a <u>counter EMF</u> because it ____________ the source.

- -

(opposes)

13. Label the expanded conductor to indicate polarity of induced EMF the instant the switch is closed.

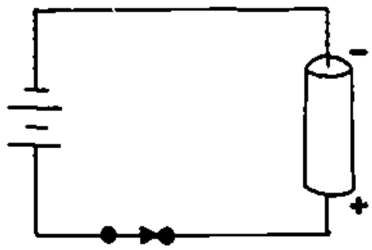


    What happens to the induced EMF in this circuit after the current has reached a steady flow and the magnetic field is no longer increasing? ____________

- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

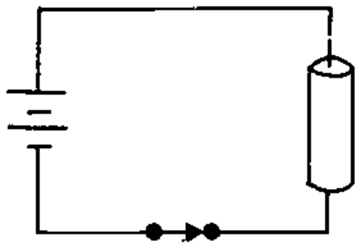
ANSWERS - TEST FRAME 13



There is no induced EMF. We no longer have relative motion between the field and the conductor. (or words to that effect)

IF ALL YOUR ANSWERS MATCH THE CORRECT ANSWERS, YOU MAY GO ON TO TEST FRAME 18. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 13 AGAIN.

14. In the circuit illustrated below, assume current has reached a steady flow and the magnetic field is steady.



Now if we open the switch, what happens?

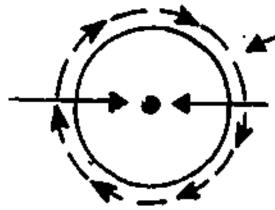
(1) Current attempts to stop.

(2) The magnetic field starts to collapse.

With the field collapsing, do we have all the requirements for inducing a voltage? ____________

(yes)

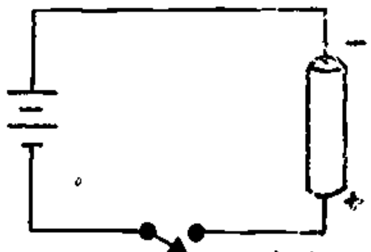
15. With the field collapsing, it is moving in toward the center of the conductor:



Applying the left-hand rule for generators again, determine the polarity of the induced EMF of the end of the conductor at which you are looking. ______________

(negative)

16. Back to the circuit again.



Okay, we have opened the switch, the field is collapsing, and the induced EMF is as indicated.

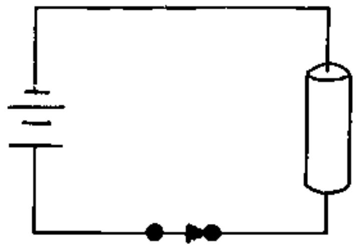
As you can see, the induced EMF caused by the collapsing field tends to cause current to flow in the ____________ direction of the original circuit current. same/opposite

(same)

17. Whereas the expanding magnetic field opposes the starting of current and attempts to stop it, the collapsing field opposes the stopping of current and attempts to ____________ it.

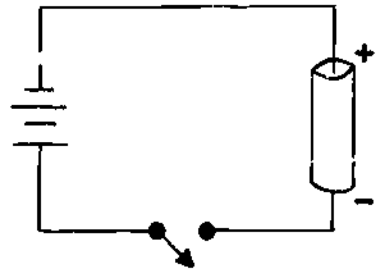
(sustain)

18. Indicate on the schematic below the polarity of the induced EMF the instant the switch is opened.



(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

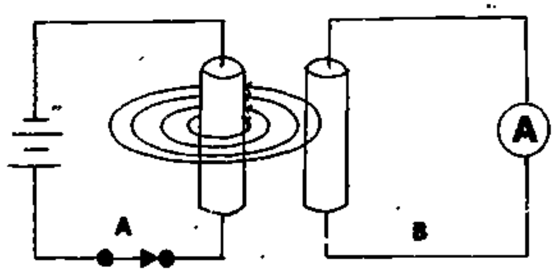
ANSWER - TEST FRAME 18



IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO ON TO TEST FRAME 20. OTHERWISE, GO BACK TO FRAME 14 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 18 AGAIN.

19. Up to this point we have been talking about inducing a voltage into the conductor that is carrying the current.

Let's place another circuit beside the first circuit, again with the expanded sections of conductor, and see what happens.

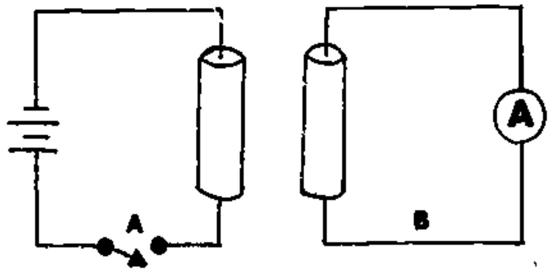


When the switch in circuit A is closed, the magnetic field begins to expand as shown. As the field expands, it cuts not only the conductor of circuit A, but also the conductor of circuit B. Is there a voltage induced in the conductor of circuit B. ______

(yes)

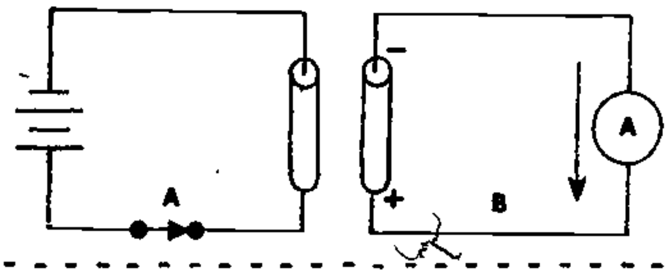
73

20. Label the expanded conductor in Circuit B to indicate the polarity of the induced EMF the instant the switch is closed in Circuit A. Indicate by an arrow the direction current will flow through the ammeter in Circuit B.



(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWER - TEST FRAME 20

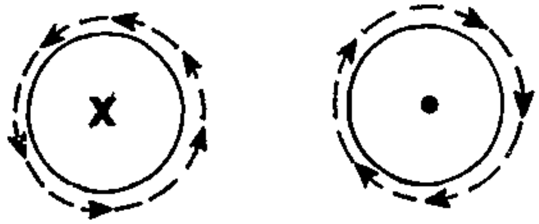


IF YOUR ANSWER MATCHES THE CORRECT ANSWER, YOU MAY GO TO TEST FRAME 28. OTHERWISE, GO BACK TO FRAME 19 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 20 AGAIN.

21. Since we have established that current flows in the second circuit, is there a magnetic field around the conductor of circuit B? ____________

(yes. Remember - any current carrying conductor has a magnetic field around it.)

22. To see the effect of this field, let's turn both conductors on end again.



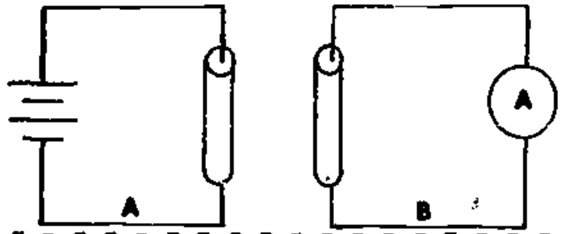
Circuit A Circuit B

Using the left-hand rule for generators, determine and state the polarity, at the end of the conductor at which you are looking, of the counter EMF induced in circuit B by the current flowing in circuit B. ____________

(negative)

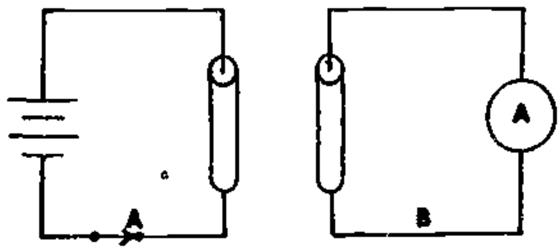
23. With this polarity, it is obvious that the counter EMF attempts to cause current to flow in the opposite direction to that of the original current. We can say, then, that this counter-EMF reduces the effect of the field of circuit A.

The self-induced counter-EMF of circuit B ___________ the effect of the magnetic field of circuit A. aids/opposes



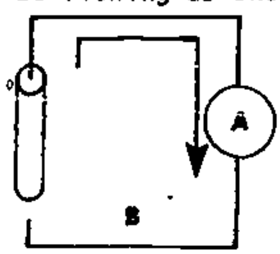
(opposes)

24. This concept is best stated in the form of a rule called Lenz's Law. It states: The direction of an induced EMF is such that it TENDS to set up a current flow whose magnetic field ALWAYS opposes a change in the field caused by the original current.



What will be the direction of current flow in circuit B when the switch in circuit A is opened? ______________

(You had to stop and think on this one. The current is going to reverse and it will be flowing as shown.)



25. You have probably noticed that in our explanations we have been using a DC source, but you have also noticed that the only time a voltage is induced is when current is either starting or stopping.

Considering this, we can say that for a voltage to be induced in a current carrying conductor, there must be a ___________ in current flow.

(change)

---

26. What type of current is continuously changing? ___________

(alternating current)

---

27. Using alternating current provides us with the necessary change of current flow to provide a continuously induced voltage. We will see more about how we make use of this phenomenon in later lessons and modules.

(Go to next frame)

---

28. Answer these items as a review of the information learned in this lesson.

a. List three factors necessary to generate an EMF in a conductor.
   1. ____________________
   2. ____________________
   3. ____________________

b. Since a magnetic field expands around a current carrying conductor as current ________ to flow, the three requirements for inducing a voltage are satisfied.

c. As current starts to flow in a conductor, the CEMF tends to ____________ the starting current.

d. The CEMF in the conductor is of the __________ polarity to the EMF that caused current flow.

e. Opening the circuit stops the current. The action of the magnetic field around the coil attempts to ____________ the current.

f. An EMF can be induced into a second conductor or circuit by the ____________ field that expands or collapses around the conductor of another circuit.

g. Lenz's Law states: The direction of an induced EMF is such that it tends to set up a current flow whose magnetic field always ____________ a change in the field caused by the original current.

- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN ON THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 28

a. 1-conductor, 2-magnetic field, 3-relative motion

b. starts

c. oppose

d. opposite

e. sustain

f. magnetic

g. opposes

IF ANY OF YOUR ANSWERS IS INCORRECT, GO BACK TO FRAME 21 AND TAKE THE PROGRAMMED SEQUENCE.

IF YOUR ANSWERS ARE CORRECT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, GO ON TO THE NEXT LESSON. IF NOT, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

SUMMARY
LESSON III

Inducing Voltage

In our study of electromagnetic induction (Module Two, Lesson III), we learned that a magnetic field, a conductor, and relative motion between them so that flux lines are cut by the conductor will induce a voltage in the conductor. The greater the rate of change of the flux as seen by the conductor, the larger the value of EMF induced. Faraday's Law states: The EMF induced or generated in a conductor is in direct proportion to the rate at which the conductor cuts the lines of magnetic flux.

We have also seen (via electromagnetism) that when current starts to flow in a conductor, a magnetic field is formed around it. If we look at an enlarged cross-section of a wire, we see that as current begins to flow, circular lines of flux build up and expand outward from the center of the wire; thus, there is the relative motion between the conductor and its internal field. Therefore, we can assume that a voltage is induced in a conductor which begins to carry a current. We can determine the polarity of the induced voltage by using the left-hand rule for generators. Since the law of conservation of energy holds, the induced EMF is a counter EMF or CEMF.

It tends to cause current to flow in a direction opposing the actual current flow. As the current is building up, the CEMF tends to hold back or choke the current from the source. Note that when the current finally reaches its maximum steady value, there is no CEMF induced, since there is no longer any relative motion between the field and the conductor.

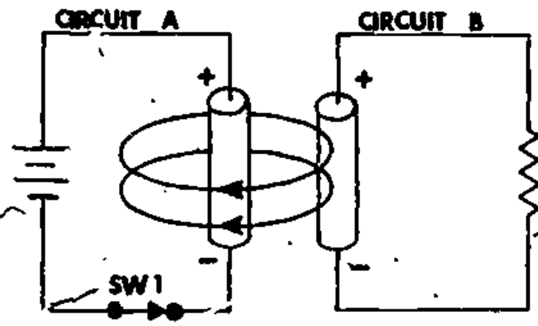
Let us now examine what happens after we open a switch in our circuit. Current stops, and the magnetic field collapses.

The same action occurs as the field collapses. Once again there is relative motion between internal portions of the conductor and the field, and an induced EMF appears, as determined by the left-hand rule for generators. IN this case, instead of tending to oppose the source voltage, it aids the original EMF polarity and attempts to keep current flowing in the circuit. Although continued current flow is not possible in an open circuit, the EMF pushes in that direction until the magnetic field is fully collapsed.

Inducing a Voltage in a Second Circuit

Suppose we take the original circuit with the enlarged section of conductor, and place it near another circuit with an enlarged

section of conductor but without a source as shown below:



If we close SW1, the magnetic lines of flux caused by the current flowing in Circuit A cut the conductor of Circuit B. Once again, we can apply our left-hand rule for generators to the enlarged portion of the conductor and determine the polarity of the voltage induced in Circuit B. This analysis indicates that a counterclockwise flow of electron current in Circuit B exists. Does this agree with the law of conservation of energy?

The effect can be summarized in Lenz's Law which states: The direction of an induced EMF is such that it tends to set up a current flow whose magnetic field always opposes a change in the field caused by the original current.

What will be the direction of current flow in Circuit B when SW1 is opened after current has reached a maximum steady value?

Note that a change in current flow, e.g., zero to a maximum (steady DC level) or the reverse, is necessary to have an induced voltage.

Since AC current is always changing, replacing the battery of Circuit A with an alternator would induce a continuous voltage in Circuit B.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, GO TO THE NEXT LESSON. IF NOT, STUDY ANOTHER METHOD OF INSTRUCTION UNTIL YOU CAN ANSWER ALL THE QUESTIONS CORRECTLY.

NAVPERS 94558-8a

BASIC ELECTRICITY AND ELECTRONICS
INDIVIDUALIZED LEARNING SYSTEM

MODULE EIGHT

LESSON IV

Inductance and Induction

Study Booklet

Bureau of Naval Personnel
January 1972

OVERVIEW
LESSON IV

Inductance and Induction

In this lesson you will study and learn about the following:

- inductance and its unit of measurement
- practical solutions
- factors that affect inductance
- induction
- factors affecting induction
- mutual inductance
- mutual induction

BEFORE YOU START THIS LESSON, PREVIEW THE LIST OF STUDY RESOURCES ON THE NEXT PAGE.

LIST OF STUDY RESOURCES
LESSON IV

Inductance and Induction

To learn the material in this lesson, you have the option of choosing, according to your experience and preferences, any or all of the following:

STUDY BOOKLET:

Lesson Narrative
Programmed Instruction
Lesson Summary

ENRICHMENT MATERIAL:

NAVPERS 93400A-1b "Basic Electricity, Alternating Current." Fundamentals of Electronics. Bureau of Naval Personnel. Washington, D.C.: U.S. Government Printing Office, 1965.

YOU MAY NOW STUDY ANY OR ALL OF THE RESOURCES LISTED ABOVE. YOU MAY TAKE THE PROGRESS CHECK AT ANY TIME.

NARRATIVE
LESSON IV

Inductance and Induction

In this lesson we will attach names and units to the concepts you have already learned.

Inductance

We learned in Lesson III of this module that when a current starts or stops flowing in a conductor or coil, there is an EMF induced. We further learned that as current is rising, the induced EMF opposes the source (tries to stop the current), and as current is decreasing, the induced EMF aids the source (tries to keep the current flowing).

Does a conductor or an inductor have the ability to oppose a change in current even though no current is flowing in the conductor? ________

Certainly! Just as you have the ability to work even while you are sleeping, so does a conductor or inductor have the ability to oppose a change in current even though a current is not flowing. This ability, then, is a physical property or a built-in characteristic of the conductor or coil.

This ability or physical property has been named inductance. More precisely, inductance is the physical property of an electrical circuit that opposes a change in current flow.

With your power supply unplugged, does the choke have inductance? ________

Choke, of course, is another name for the inductor or coil, and it too has inductance even in a de-energized circuit.

Have you ever used a wheelbarrow? Remember how hard it was to get it started when it was loaded? It was hard to stop once you got it rolling, too, wasn't it? Just remember that inductance has that same effect on current. It opposes the current when it is increasing, and aids or tries to sustain current when it is decreasing.

Unit of Measurement

Does a coil have the same amount of inductance as a straight conductor? ____________

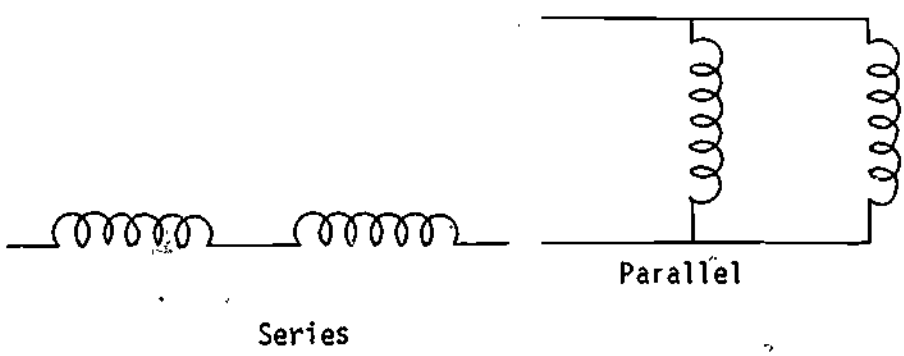
No! Of course not! So, if all conductors or inductors do not have the same amount of inductance, we must have some way of measuring this ability.

The unit of measurement for inductance is the henry. A conductor or coil is said to have 1 henry of inductance if 1 volt is induced into the conductor or coil when the current changes at the rate of 1 ampere per second.

The symbol for inductance is L, and the abbreviation for henry is h. We can state, then, that the coil has an inductance of 1 henry or L = 1h. Frequently we will be dealing with components whose inductance values are much less than 1 henry. We will use the millihenry (mh) or the microhenry (μh) where applicable. (Remember, milli means 1/1,000 and micro means 1/1,000,000.)

Solving for L

Just as resistors, inductors may be connected in either series or parallel.



To solve for total inductance in a circuit, you use the same rules you learned for resistance, namely:

1. Inductance is additive in series.
2. Inductance in parallel may be found by any of three methods:

a. any number of inductors of equal value:

$$L_T = \frac{L}{n} \quad \text{(inductance of one inductor)}$$

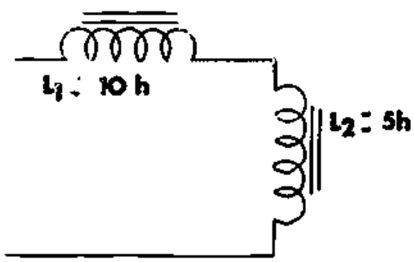
b. two inductors of unequal value:

$$L_T = \frac{L1 \times L2}{L1 + L2}$$

c. any number of inductors:

$$L_T = \frac{1}{\frac{1}{L1} + \frac{1}{L2} + \frac{1}{L3} + \dots \frac{1}{L_n}}$$

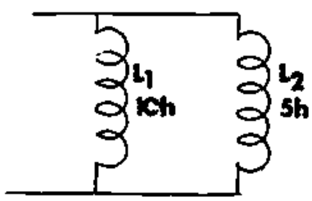
Find L_T in this circuit.



Since it is a series circuit, we find L_T by simple addition:

$L_T = L1 + L2 = 10h + 5h = 15h.$

Let's try this one. L_T = ________



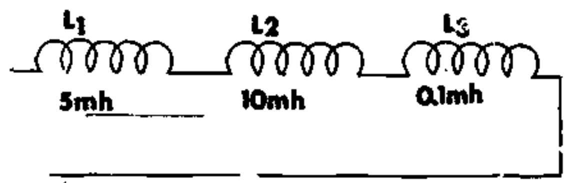
Since this one is a parallel network, we find the equivalent inductance by either the product-over-the-sum or the sum-of-the-reciprocals method.

$$L_T = \frac{L1 \times L2}{L1 + L2} = \frac{10h \times 5h}{10h + 5h} = \frac{50}{15} \qquad L_T = 3.33$$

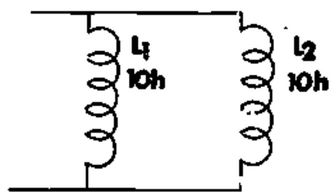
or

$$L_T = \frac{1}{\frac{1}{L1} + \frac{1}{L2}} = \frac{1}{\frac{1}{10} + \frac{1}{5}} = \frac{1}{\frac{1}{10} + \frac{2}{10}} = \frac{1}{\frac{3}{10}} = \frac{10}{3} = 3.33h$$

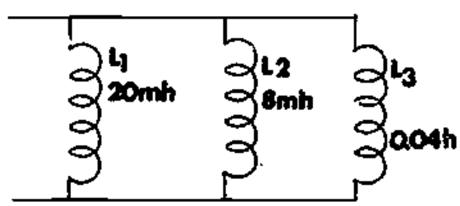
Solve these circuits for L_T.

1. 

$L_T =$ ________

2. 

$L_T =$ ________

3. 

$L_T =$ ________

Your answers should agree with these:

1. 15.1mh
2. 5h
3. 5mh

Factors That Affect Inductance

Since inductance is a physical property, it should be safe to assume that any factors affecting inductance must also be physical factors.

Does the amount of current flow affect the inductance of a coil? ____________

No! Certainly not! Remember we decided the ability (inductance) existed without current flow. Then current flow must not affect the amount of the inductance.

In an earlier lesson, we discussed factors that affect flux density of the magnetic field of a coil. These same factors, except current, affect the inductance. They are:

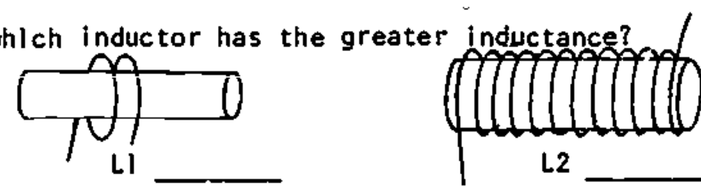
1. The number of turns of the coil. The greater the number of turns, the greater the amount of inductance. A coil, then, has more inductance than a straight wire.

L1 L2

L2, having more turns, has more inductance than L1.

2. Cross-sectional area of the core. The greater the cross-sectional area, the greater the amount of inductance.

Which inductor has the greater inductance?



L1 ________ L2 ____________

Answer: L2

3. Permeability of the core. The greater the permeability of the core material, the more inductance.

Which inductor has the greater inductance?

L1 ________ L2 ________

Answer: L1 because it has an iron core which has a higher permeability than air.

4. <u>Length of the core</u>. The longer the core, the less the amount of inductance. Notice that this is an inverse relationship.

5. <u>Coil turns spacing</u>. The closer the turns, the greater the amount of inductance.

Induction

While <u>inductance</u> is a <u>physical</u> property, <u>induction</u> is the <u>action</u> of inducing a voltage within a conductor or coil. Inductance does not require current flow, while induction does require current flow. We must have the <u>action</u> of the electrons within the conductor to have a magnetic field, and a magnetic field is one of the requirements for inducing a voltage. We must further have the <u>action</u> of the conductor's being cut by the magnetic lines of flux, and this cutting action is obtained only when the current is <u>changing</u> in some way

Induction, then, is the <u>action</u> of inducing a voltage when current is changing in a circuit. The induced voltage, as previously stated, is called counter EMF and abbreviated CEMF.

Factors Affecting Induction

The factors which affect the amount of induction are the same factors that affect flux density, and therefore are the same factors which affect inductance plus a change in current. Again, they are:

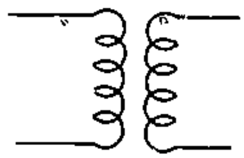
1. the number of turns in the coil
2. the cross-sectional area of the core
3. the permeability of the core material
4. the length of the core
5. coil turns spacing
6. the rate of change in current flow

Note that in the factors affecting flux density, we simply said the amount of current, whereas here we said the amount of <u>change</u> of current. What we mean here is: If, for a given inductor, we have a rate of change of current of 1 ampere per second (current increases or decreases 1 ampere in 1 second) and we induce 1 volt, then a rate of change of 2 amperes per second would induce 2 volts. We increase the amount of induction -- <u>not</u> the amount of inductance.

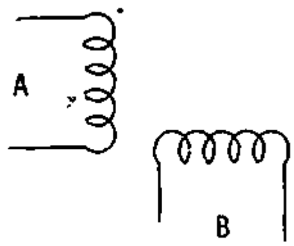
Mutual Inductance

When two coils are physically positioned so that the lines of flux of one can cut the turns of the second coil in such a manner as to induce a voltage, they exhibit mutual inductance. All this really means is that the lines of flux from each coil can act upon the

turns of the other coil to induce a voltage.



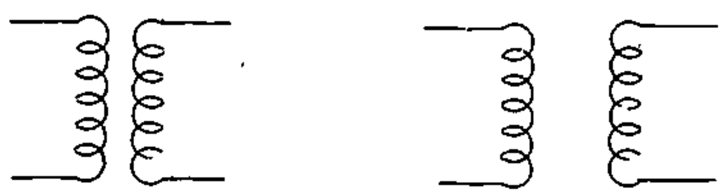
These coils exhibit the physical property of mutual inductance.



These two coils are positioned in such a manner that the lines of flux of one cannot induce a voltage into the other; therefore, they do not exhibit mutual inductance.

While the symbol for inductance is L, the symbol for mutual inductance is M. Both L and M, are measured in henrys.

The amount of mutual inductance of two coils is affected by their proximity (how close they are). This determir .s what percentage of the flux lines of one coil cut the turns of the other coil, and this percentage is called the coefficient of coupling. The greater the coefficient of coupling, the greater the amount of mutual inductance for a given pair of coils. The maximum coefficient of coupling is 1, which means that 100% of the lines of flux of one coil cut all the turns of the other coil.



A B

Assuming the coils are identical in each case, which pair has the greater mutual inductance? ________

'air A. The coils are closer together, thus having a greater coefficient of coupl'ng.

Mutual Induction

Recall that induction was the action of inducing a voltage. Then mutual induction must also be action. And it is; it is the action of transferring energy from one electrically isolated circuit to another.

Mutual induction, like induction, is dependent upon the existance of a changing current flow. Without the motion, there is no induced voltage and no energy transfer.

Mutual induction is the action which takes place in transformers, which you will study in Module Ten.

AT THIS POINT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, YOU HAVE MASTERED THE MATERIAL AND ARE READY TO TAKE THE MODULE TEST. SEE YOUR LEARNING SUPERVISOR.

IF YOU DECIDE NOT TO TAKE THE PROGRESS CHECK AT THIS TIME, OR IF YOU MISSED ONE OR MORE QUESTIONS, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU HAVE ANSWERED ALL THE PROGRESS CHECK QUESTIONS CORRECTLY. THEN SEE YOUR LEARNING SUPERVISOR AND ASK TO TAKE THE MODULE TEST.

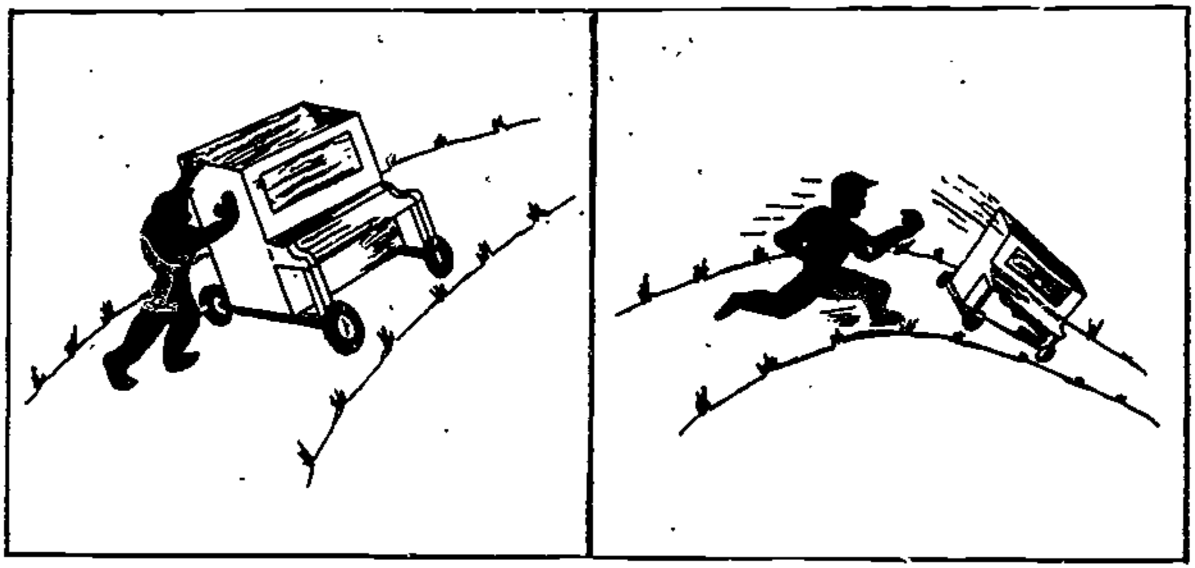
PROGRAMMED INSTRUCTION
LESSON IV

Inductance and Induction

TEST FRAMES ARE 7, 18, 23, 34, 37, 47, 50 AND 51. AS BEFORE, GO FIRST TO TEST FRAME 7 AND SEE IF YOU CAN ANSWER ALL THE QUESTIONS THERE. FOLLOW THE DIRECTIONS GIVEN AFTER THE TEST FRAME.

---

1. Have you ever pushed a piano? Pianos are hard to start, but once they are in motion, they move easily. In fact, once a piano is moving, it is hard to stop. You use more energy to start a piano moving than you use to keep it moving. You also need more energy to stop a piano once it is moving than you need to keep it moving. The need for this extra energy is to overcome inertia. What is inertia? A body at rest tends to remain at rest; a body in motion tends to stay in motion.



Electrical circuits have a property which is very similar to inertia. Inertia is the property of an object to oppose any change in its direction of motion. Some electrical circuits have a property which opposes change in current. If current in a circuit increases, a force in that circuit opposes the increase. If current in a circuit decreases, a force in that circuit opposes the decrease. The property of a circuit that opposes any change of current in that circuit is called inductance.

Inductance is the property of a circuit that opposes any ____________ of ______________.

(change; current)

2. As the current flow through a conductor increases or decreases in value, the magnetic field about that conductor is expanding or collapsing. The changing magnetic field causes a self-induced voltage known as counter EMF (CEMF). The counter EMF opposes the applied voltage, thus opposing the change in circuit _____.

(current)

3. Lenz's Law states:

The voltage induced in a circuit by a changing current always opposes the change causing it. This statement is the basis for the explanation of the property of _____________.

(inductance)

4. The voltage induced in a circuit by a changing current which opposes the applied voltage is called _______________.

(counter EMF)

5. Inductance is the _____________ of a circuit that opposes any _____________ of _______________.

(property; change; current)

6. The voltage induced in a circuit by a changing current always opposes the change causing it.

This is a statement of _______________ _______________.

(Lenz's Law)

7. Which of the following statements best states Lenz's Law?

____ a. The voltage induced in a circuit by a changing current always opposes the change causing it.

____ b. The inductance in a circuit always opposes the change causing it.

- -

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWER GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWER - TEST FRAME 7

a. The voltage induced in a circuit by a changing current always opposes the change causing it.

- -

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, GO TO TEST FRAME 18. OTHERWISE, GO BACK TO FRAME 1 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 7 AGAIN.

8. The property of a circuit that opposes any change of current in that circuit is called inductance. What property of a circuit would oppose a change of current within a circuit from 4 amps to 2 amps?

____

- -

(inductance)

9. The voltage induced by a changing current in a circuit opposes the applied voltage. This induced voltage is known as ______________________.

- -

(counter EMF)

10. Inductance is the measure of a circuit's ability to induce voltage in itself. The amplitude of induced voltage depends upon the amount of magnetic lines which link or cut portions of that circuit. The symbol for inductance is L (for Linkage). The symbol representing the measure of a circuit's ability to induce a voltage is ________.

- -

(L)

11. Inductance (L) is measured in henrys. The abbreviation for 1 henry is h. When a change of current of 1 ampere per second induces a voltage of 1 volt, we have 1 henry of inductance. Inductance (L) is measured in ______________ which is abbreviated __________.

(henrys; h)

12. Frequently, very small values of inductance are used. Using the prefixes you have previously learned, write the abbreviations for 1/1,000 of 1 henry _______________, and 1/1,000,000 of 1 henry ___________.

(1mh; 1µh)

13. The property of a circuit that opposes any change of current flowing in that circuit is known as ________________.

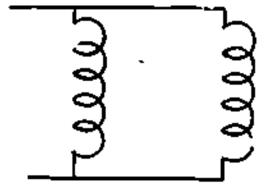
(inductance)

14. The symbol for inductance is _____________; the unit of measurement for inductance is the ________________, which is abbreviated _________________.

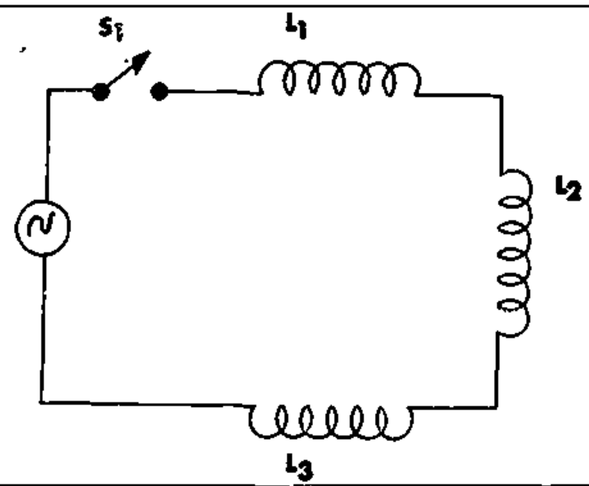
(L; henry; h)

15. In circuits having more than one inductor, we must be able to compute total inductance.

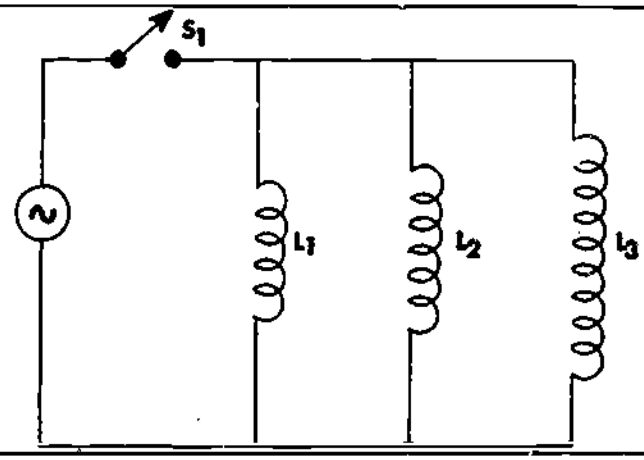
Inductors may be connected in either series 

or parallel  configurations.

Draw a circuit of three inductors connected in series with an AC power source and switch.



16. Draw a circuit with three inductors in parallel with an AC power source and switch.

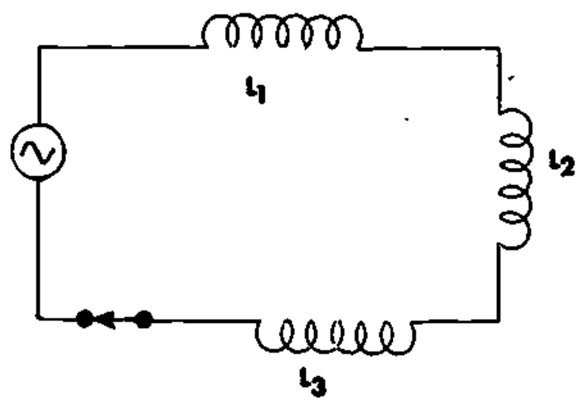


99

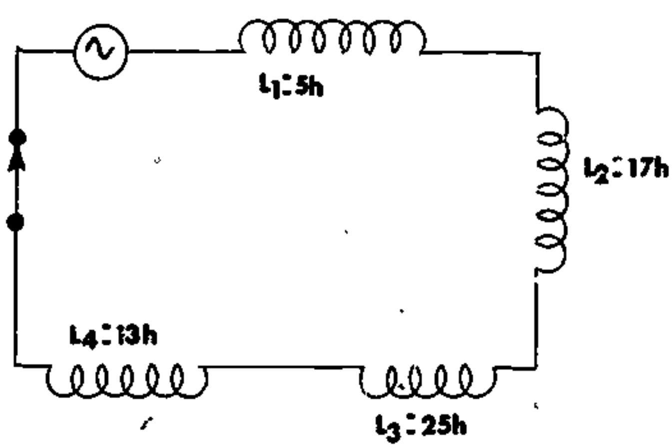
17. When you solve for total inductance in a circuit, you use the same rules that apply to finding total resistance in a circuit. Series circuit: $R_T = R1 + R2 + R3$; Parallel Circuit:

$$R_T = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{Rn}}.$$

For example, series inductance requires the same formula as series resistance except for the symbol: $L_T = L1 + L2 + L3$.



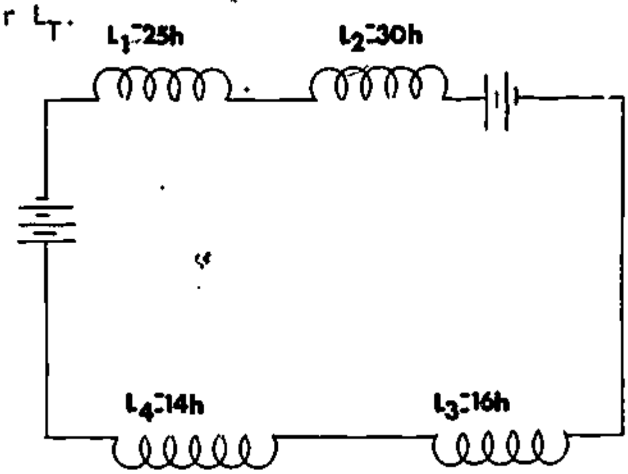
What is the total inductance of the following circuit?



L_T = ______________

(L_T = 60h)

18. Solve for L_T.



L_T = ____________h

(THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWER - TEST FRAME 18

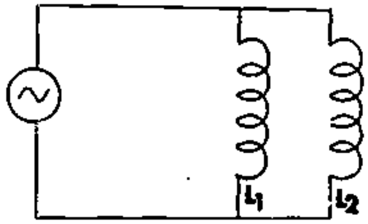
$L_T = 85$ft

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, GO TO TEST FRAME 23. OTHERWISE, GO BACK TO FRAME 8 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 18 AGAIN.

19. Solving for total inductance in parallel requires the same formulas as resistance in parallel.

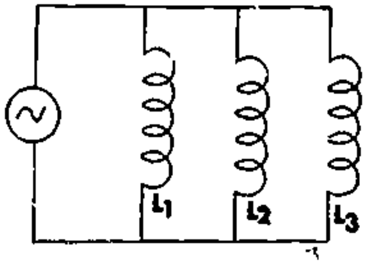
Examples:

A (2 branch)



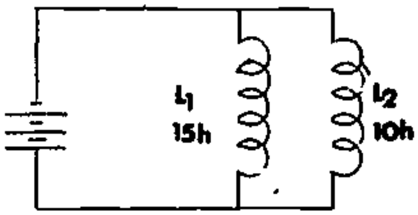
$$L_T = \frac{L1 \times L2}{L1 + L2}$$

B (3 branch or more)



$$L_T = \frac{1}{\frac{1}{L1} + \frac{1}{L2} + \frac{1}{L3}}$$

Solve for L_T in this two-branch parallel circuit.

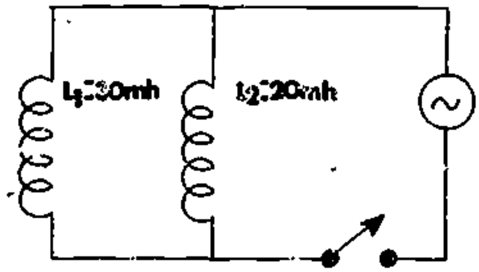


L_T = ____________

(6h)

103

20. What is the total inductance of the circuit below?



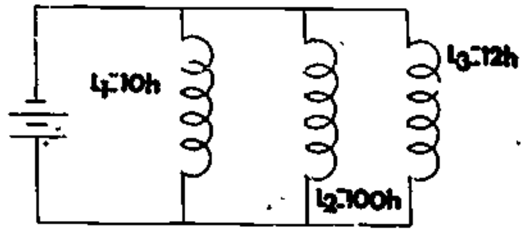
L_T = ________

(12mh)

21. You will notice that total inductance of a parallel network will always be less than the smallest inductor.

Total inductance in the circuit below will be:

____ a. greater than the value of L3
____ b. between the values of L1 and L2
____ c. less than the value of L1
____ d. the values of L1 + L2 + L3



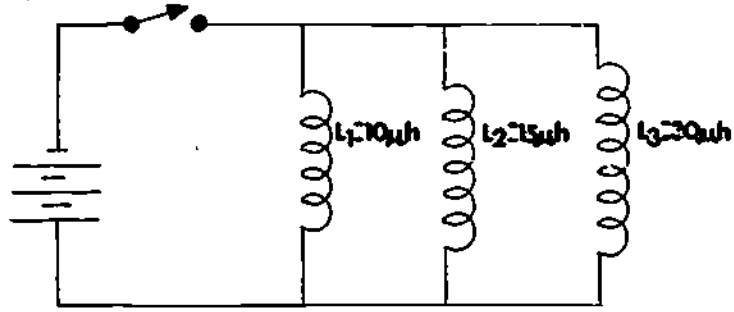
(c) less than the value of L1

22. In a three-branch circuit, L_T is ____________ than the smallest inductor.

(smaller)

104

23. In the circuit below, L_T is equal to:



____ a. 17.98μh.

____ b. 5μh.

____ c. 9.50μh.

____ d. 55μh.

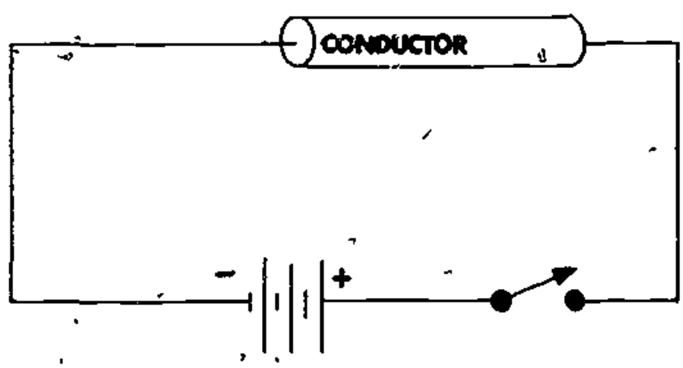
(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWERS - TEST FRAME 23

b. 5µh

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, GO TO TEST FRAME 34. OTHERWISE, GO BACK TO FRAME 19 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 23 AGAIN.

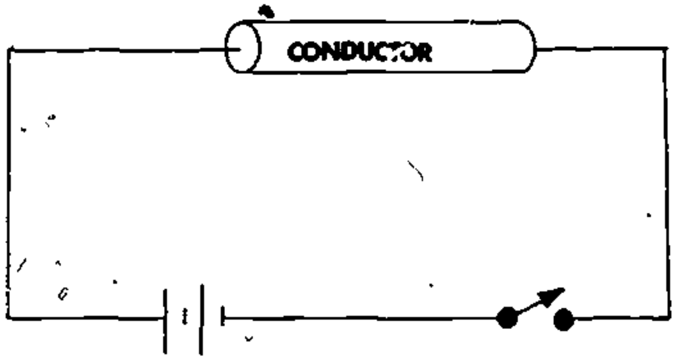
24. In the circuit shown below, when the switch is closed, current does not build up immediately because the counter EMF in the conductor ____________ the applied voltage.
(aids/opposes)

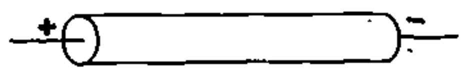


(opposes)

25. The polarity of the counter EMF in the conductor in the figure in frame 24 is such that it opposes the applied voltage when the circuit is energized.

Label the polarity of the counter EMF which is induced in the expanded conductor when the switch is closed.





---

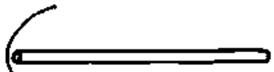
26. The property of inductance affects DC circuits only at the time they are turned on or off. However, AC circuits are always affected by the property of inductance because current in an AC circuit is always ________.

(changing)

27. The amount of induced voltage in an AC circuit can be increased by increasing the length of the conductor that is affected by the changing magnetic field.

Which diagram below shows the greatest length of conductor in a given area?

____ a.

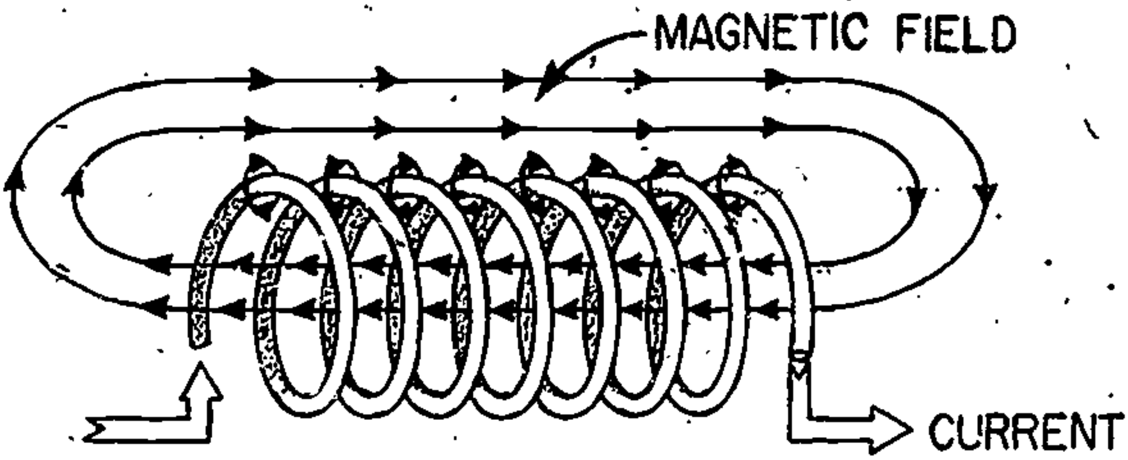


____ b.

____ c.

(c)

28. By winding a conductor into a coil, the amount of voltage induced is greater than it would have been if the conductor were a straight piece of wire.



A coil concentrates the magnetic field about it; therefore, a greater ____________ is induced in the coil.

(voltage)

29. A coil of wire that is wound so that it has a specific amount of inductance is called an <u>inductor</u>. You may also see it referred to as a <u>choke</u> or simply a <u>coil</u>. A coil of wire that has a specific amount of inductance is called an ____________.

(inductor)

30. Inductors are usually rated in <u>henrys</u>, <u>millihenrys</u>, or <u>microhenrys</u>.

A choke is normally rated in units of ________________, ________________ or ________________.

(henrys; millihenrys; microhenrys)

31. Since inductance is a physical factor (built in), the factors that affect inductance must be ____________ factors.

(physical)

32. The amount of inductance of a coil is dependent upon five factors:

1) the number of turns of the coil
2) the cross-sectional area of the core
3) the permeability of the core material
4) the length of the core material
5) the spacing between coil turns

Now, think about this for a moment: Considering the things you know about inductance, and the factors you see listed above, indicate which factors have a directly proportional relationship with inductance and which an inversely proportional relationship.

Directly Proportional:	Inversely Proportional:
____________________	____________________
____________________	____________________
____________________	____________________

- -

(Directly Proportional:	Inversely Proportional:
1) number of turns of the coil	1) the length of the core material
2) the cross-sectional area of the core	2) the spacing between coil turns
3) the permeability of the core material)	

110

33. You may have recognized these factors as the same factors that affect flux density that you learned earlier. If you did, then the last frame was easy for you. You simply realized that flux density is increased by an increase in:

1) the number of turns of the coil
2) the cross-sectional area of the core
3) the permeability of the core material,

and will be decreased by an increase in

4) the length of the core material (more reluctance)
5) the spacing between coil turns.

You will recall there were six factors affecting flux density, but we see only five affecting inductance.

What factor affects flux density that does not affect inductance

______________.

(amount of current)

---

34. List the five factors that determine the inductance of a coil.

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

111

ANSWERS - TEST FRAME 34

1. number of turns of the coil
2. cross-sectional area of the core
3. permeability of core material
4. length of core
5. the spacing between coil turns

IF YOUR ANSWERS MATCH THE CORRECT ANSWERS, GO TO TEST FRAME 37. OTHERWISE, GO BACK TO FRAME 24 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 34 AGAIN.

---

35. The amount of current does not affect the ability (inductance) of a coil to induce a voltage. It does, however, have an effect on induction, which is the action of inducing a voltage.

Since current is movement, we can say that ____________ is required in order to have induction.

(motion)

---

36. We discovered earlier that the current must be changing in value to have the relative motion necessary to induce a voltage.

Let us think of what induction is!

Induction is the __________ of inducing a voltage.

(action)

37. In your own words, state the difference between inductance and induction. ____________________

____

____

(THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWER - TEST FRAME 37

Inductance is a physical property and is a measure of the ability of a circuit or component to induce a voltage, while induction is the action of inducing that voltage. Inductance does not require current flow, whereas induction does. (or words to that affect)

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, GO TO TEST FRAME 47. OTHERWISE, GO BACK TO FRAME 35 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 37 AGAIN.

38. Name the six factors which affect induction.

1. ______
2. ______
3. ______
4. ______
5. ______
6. ______

(1. the number of turns in the coil; 2. the cross-sectional area of the core; 3. the permeability of the core material; 4. the length of the core; 5. the rate of change in current flow; 6. spacing between coil turns)

This should have been pretty easy even though the factors had not been listed for you as such. The same factors that affect the ability (inductance) must also affect the action (induction). The amount of change of current flow is the one added factor.

39. A circuit induces voltage into itself when the current changes. When two or more circuits or components (coils) are close to each other, changing current in one circuit can induce voltage in another circuit. This is called mutual inductance. The mutual inductance between circuits is measured in henrys. When a change of 1 ampere per second in 1 circuit induces a voltage of 1 volt in another circuit, there is a mutual inductance of 1 henry. The symbol for mutual inductance is M.

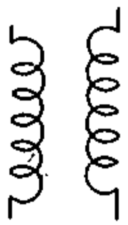
Voltage induced in a conductor because of a changing magnetic field around another conductor is induced because of ________ ________.

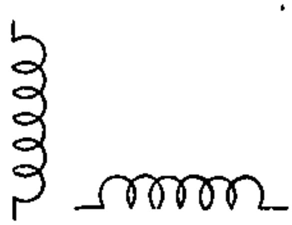
(mutual inductance)

40. When two coils are physically positioned so that lines of flux of one can cut the turns of the second coil in such a manner as to induce a voltage, they exhibit mutual inductance.

Which of the below pairs of coils exhibit mutual inductance?

____ a. ____ b.



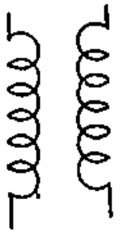


(a)

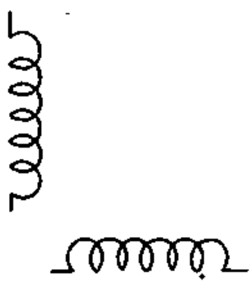
IF YOU ANSWERED THIS CORRECTLY AND UNDERSTOOD THE REASON, GO TO FRAME 42. IF NOT, GO TO FRAME 41.

115

41. Let us take a look at those pairs of coils again.



These two coils are positioned in such a manner that the lines of flux from one can cut the turns of the other, and in so cutting, produce a voltage. It is possible that they be placed far enough apart so that none of the lines of flux cut the other, but this is not apparent here.



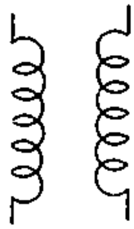
These coils, on the other hand, are positioned so that the lines of flux of one may cut the turns of the other, but not in such a manner as to induce a voltage. There is a cancelling effect and thus no mutual inductance.

(Go to next frame.)

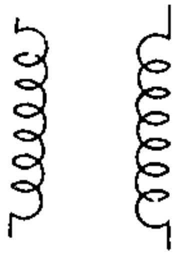
42. The amount of mutual inductance is dependent upon the amount of inductance of the coils and the proximity (how close they are) of the coils. In other words, the closer the coils, the more ________________.

(mutual inductance)

43. Spacing the coils closer causes more lines of flux from one coil to cut the other coil. The percentage of lines of flux of one coil that actually cut the other coil is called the coefficient of coupling. A coefficient of coupling of 1 means that 100% of the lines of flux of one coil cut all the turns of the other coil.



____ A.



____ B.

Assuming the coils are identical in each case, which pair has the greatest mutual inductance? ____________

(A)

44. M is the symbol for ____________ ____________.

(mutual inductance)

45. Mutual inductance is the ability of a changing magnetic field in one conductor to induce a ____________ in another conductor.

(voltage)

46. The symbol for mutual inductance is ____________.

(M)

117

47. What two factors affect the mutual inductance of two coils?

1. ____________________

2. ____________________

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

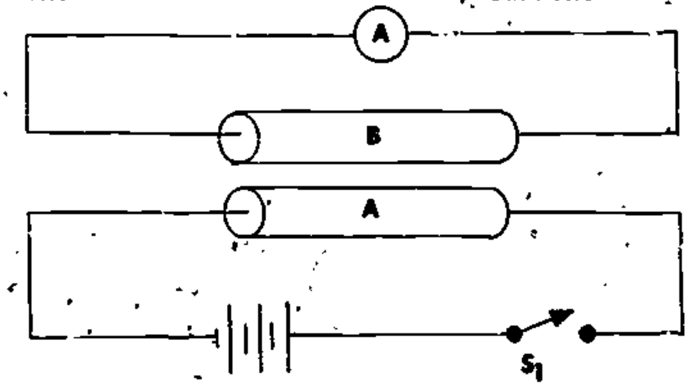
ANSWERS - TEST FRAME 47

1. the inductance of each coil

2. the coefficient of coupling

IF YOUR ANSWERS MATCH THE CORRECT ANSWERS, GO TO TEST FRAME 50. OTHERWISE, GO BACK TO FRAME 38 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 47 AGAIN.

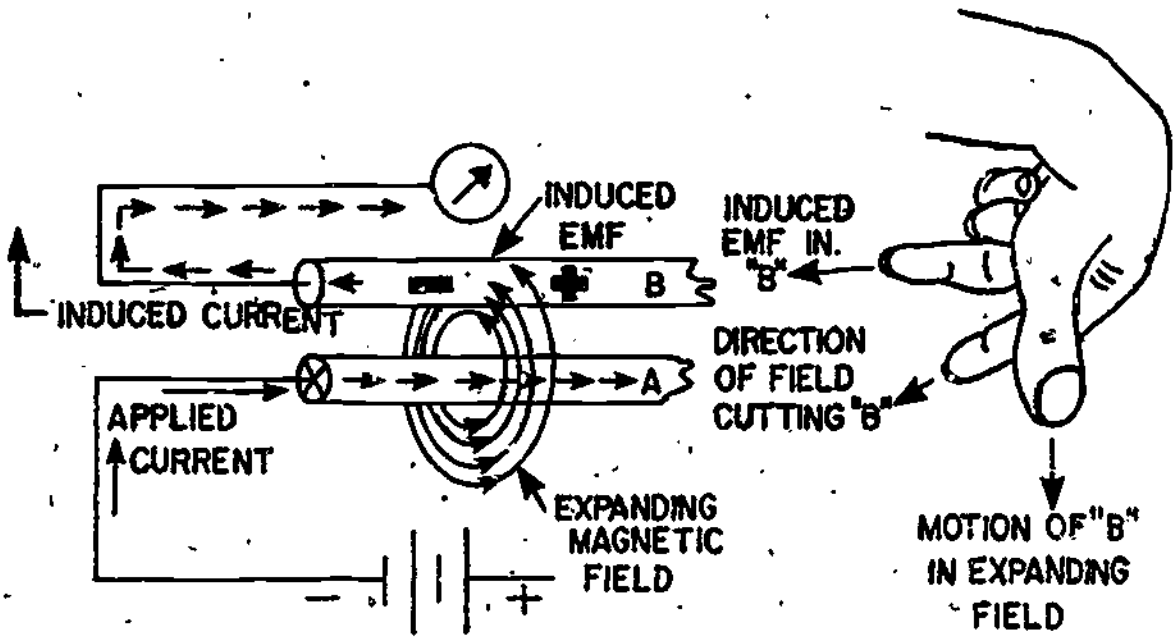
48. Now, let us look at a circuit that has mutual inductance. Shown below are two circuits with part of the conductor of each expanded for a better look. The expanded sections are marked A and B. Wire A is connected to a battery through a switch (S1). Wire B is near wire A, but is not connected to any voltage source. An ammeter is installed in series with wire B. The ammeter will indicate any current flow in wire B.



At the moment the switch (S1) is closed, current starts to flow in wire A. Lines of force expand around wire A, and as they expand, cut wire B as shown on the next page. A voltage is induced in wire B. The polarity of the induced voltage in wire B can be determined by using the left-hand rule for generators. The current in wire B is opposite in direction to the current in wire A.

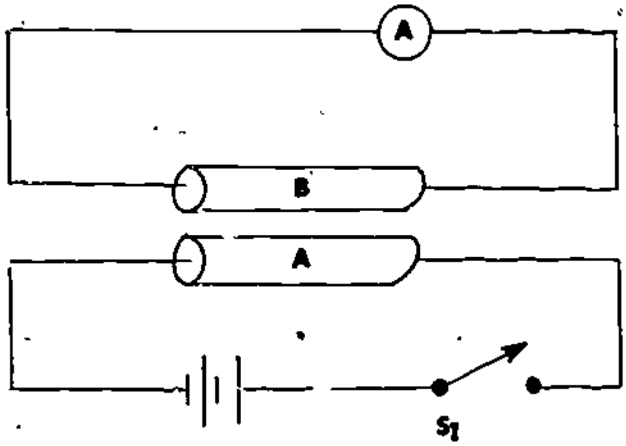
(Continued on next page)

48. (con't.)



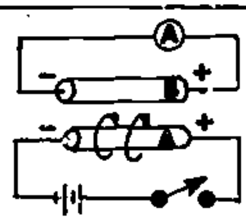
Considering the relationship between inductance and induction, what would you call this action of inducing a voltage into an isolated circuit or component? ________ ________

(mutual induction)

49. 

1. When $\overline{SI}$ is closed, the expanding magnetic field around wire A will induce a voltage in wire B.
2. The induced voltage in wire B will cause current (induced current) to flow through the ammeter (A).
3. The left-hand rule for generators can be used to find the polarity of induced voltage in wire B.
4. The induced voltage acts as a source for current in circuit B.

Indicate the direction of current flow through the expanded conductors A and B, and show polarities of induced EMF in both and direction of the magnetic field around conductor A.



50. In your own words describe the difference between mutual inductance and mutual induction.

(THIS IS A TEST FRAME. COMPARE YOUR ANSWER WITH THE CORRECT ANSWER GIVEN AT THE TOP OF THE NEXT PAGE.)

ANSWER - TEST FRAME 50

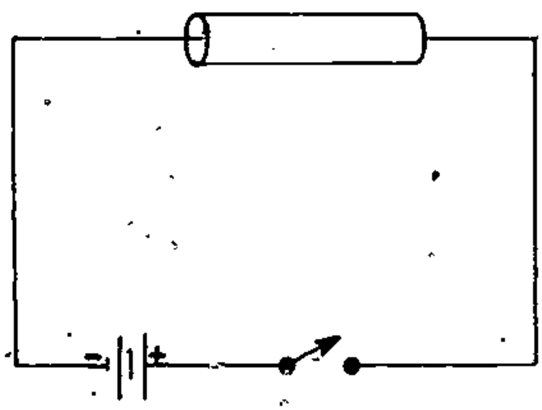
Mutual inductance is the ability of a circuit or component to induce a voltage into another isolated circuit or component; mutual induction is the action of one circuit or component inducing a voltage into another circuit or component. Mutual inductance does not require current flow; mutual induction does. (or words to that effect).

IF YOUR ANSWER MATCHES THE CORRECT ANSWER, GO TO TEST FRAME 51. OTHERWISE, GO BACK TO FRAME 48 AND TAKE THE PROGRAMMED SEQUENCE BEFORE TAKING TEST FRAME 50 AGAIN.

---

51. Answer these items.

a. Inductance is the ____________ of a circuit that ____________ any change in ____________.
b. The symbol for inductance is ____________. The unit of inductance is ____________ whose symbol is ____________.
c. The property of a circuit that opposes any change in current in that circuit is called ____________.
d. Label the polarity of the CEMF in the expanded conductor in the schematic below at the instant the switch is closed.



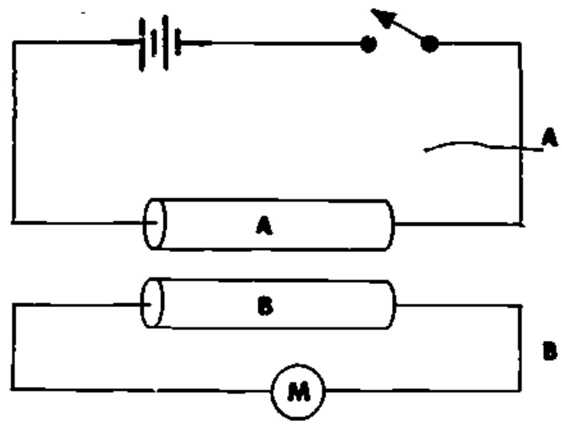
e. List five factors that determine the inductance of a coil. (any order)

1. ____________
2. ____________
3. ____________
4. ____________
5. ____________

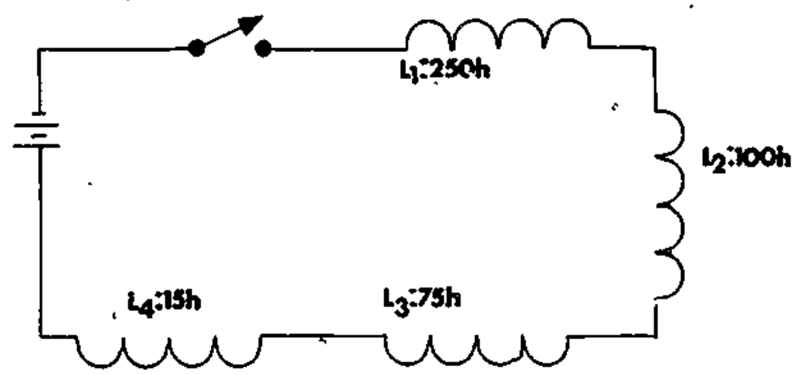
(CONTINUED NEXT PAGE)

51. (Continued)

f. The symbol for mutual inductance is ________________.
g. A changing magnetic field around a coil is caused by a changing ____________ through the coil.
h. The changing magnetic field around a coil will induce a voltage into a nearby coil because the coils have ________.
i. The factors that determine the mutual inductance between two coils are ____________ and ______________.
j. On the drawing shown, label the polarity of the induced voltage in expanded conductor B and draw an arrow indicating current flow through the meter in circuit B when the switch in circuit A is closed.



k. Solve for L_T in the circuit below. (Assume no mutual inductance.)

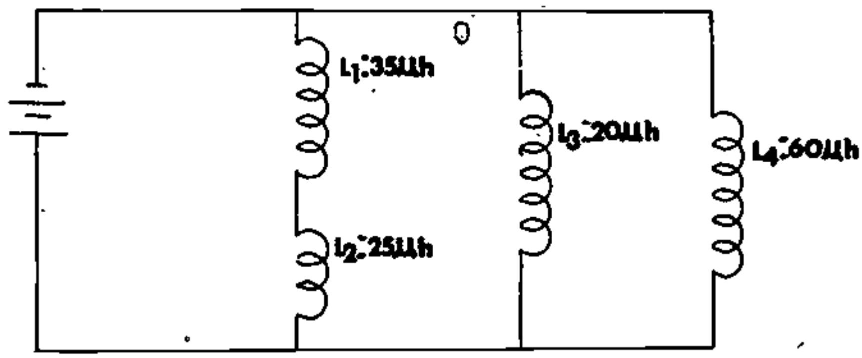


L_T = ______________________________

(CONTINUED NEXT PAGE)

51 (Continued)

1. Solve for L_T.

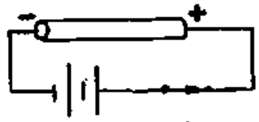


L_T = ______________

(THIS IS A TEST FRAME. COMPARE YOUR ANSWERS WITH THE CORRECT ANSWERS GIVEN AT THE TOP OF THE NEXT PAGE.)

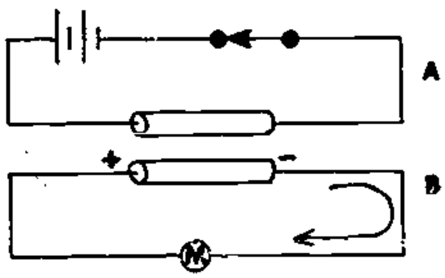
ANSWERS - TEST FRAME 51

a. property; opposes; current
b. L; henry; h
c. inductance
d.



e. 1) the number of turns in the coil
   2) the cross-sectional area of the core
   3) the permeability of the core material
   4) the length of the core
   5) spacing between coil turns
f. M
g. current
h. mutual inductance
i. the inductance of each coil, the coefficient of coupling

j.



k. $L_T = 440h$
l. $L_T = 12\mu h$

IF YOUR ANSWERS ARE INCORRECT, TAKE THE PROGRAMMED SEQUENCE AGAIN.

IF YOUR ANSWERS ARE CORRECT, YOU MAY TAKE THE PROGRESS CHECK, OR YOU MAY STUDY ANY OF THE OTHER RESOURCES LISTED. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL THE QUESTIONS CORRECTLY, YOU HAVE MASTERED THE MATERIAL AND ARE READY TO TAKE THE MODULE TEST. SEE YOUR LEARNING SUPERVISOR.

IF YOU DECIDE NOT TO TAKE THE PROGRESS CHECK AT THIS TIME, OR IF YOU MISSED ONE OR MORE QUESTIONS, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU HAVE ANSWERED ALL THE PROGRESS CHECK QUESTIONS CORRECTLY. THEN SEE YOUR LEARNING SUPERVISOR AND ASK TO TAKE THE MODULE TEST.

SUMMARY
LESSON IV

Inductance and Induction

We will now name and attach units to the concepts of induction already studied. We first note that a conductor (or coil) has the ability to oppose a change in current flow even though no current is flowing in the conductor or coil. (This is similar to a resistor having a certain resistance value though it may be carrying no current.) The physical ability to oppose a change in current flow is called inductance. The unit of measure for inductance is the henry.

By definition, a conductor or coil is said to have 1 henry of inductance if 1 volt is induced in the conductor or coil when the current changes at the rate of 1 ampere per second. The symbol of inductance is L, and the abbreviation for henry is h.

Thus if a coil has an inductance of 1 henry: L = 1h. We frequently deal with components whose inductance values are much less than 1h. We then use millihenry (mh) and microhenry (uh) as applicable.

Solving for L

Since inductors are components, they may be connected either in series or parallel arrangement. To solve for total inductance of a circuit, our basic principles lead to the same combining rules as for resistors, namely:

1) Inductance is additive in series.
2) Inductance in parallel is given by:

$$L_T = \frac{1}{\frac{1}{L1} + \frac{1}{L2} + \dots \frac{1}{L_n}},$$

or for two inductors,

$$L_T = \frac{L1 \times L2}{L1 + L2},$$

or for n equal inductors,

$$L_T = \frac{L_1}{n},$$

where L_1 is the inductance of any one inductor.

The factors that affect inductance are:

127

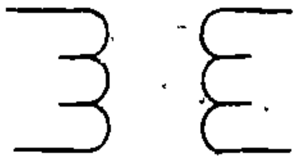
Direct	(1) The number of turns of the coil (2) The cross-sectional area of the core (3) The permeability of the core
Inverse	(4) The length of the core (5) Coil turns spacing

While Inductance is a physical property, Induction is the action of inducing a voltage within a conductor or coil. Note that Inductance requires no current, but Induction does.

The factors affecting Induction are the above five, plus a sixth, the rate of change of current flow.

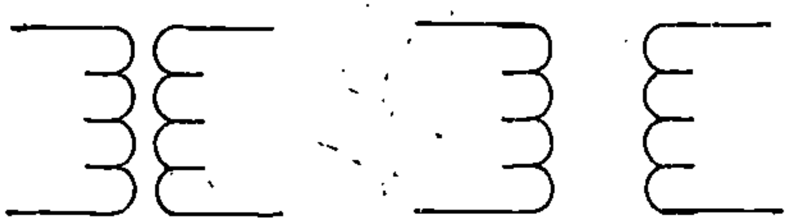
Mutual Inductance

Mutual Inductance describes the case in which two coils are physically positioned so that the lines of flux of one can cut the turns of the second. For example, if the configuration shown below exists,



we have the property of mutual inductance, M. It is also measured in henrys but now an EMF is induced into two or more circuits or components.

The amount of mutual inductance of two coils is affected by their proximity (how close they are). This determines what percentage of the flux lines of one coil cut the turns of the other coil, and this percentage is called the coefficient of coupling. The greater the coefficient of coupling, the greater the amount of mutual inductance. The maximum coefficient of coupling is 1, which means that all the lines of flux of one coil cut all the turns of the other coil.



A B

Assuming the coils are identical in each case, which pair has the greatest mutual inductance? ____________

Pair A. They are closer together thus having a greater coefficient of coupling.

Mutual Induction

Recall that induction is the action of inducing a voltage. Then mutual induction must also be action. And it is; it is the action of transferring energy from one electrically isolated circuit to another.

Mutual induction, like induction, is dependent upon the existance of a changing current flow. Without the change, there is no induced voltage and no energy transfer.

Mutual induction is the action which takes place in transformers, which you will study in Module Ten.

AT THIS POINT, YOU MAY TAKE THE LESSON PROGRESS CHECK, OR YOU MAY STUDY THE LESSON NARRATIVE OR THE PROGRAMMED INSTRUCTION OR BOTH. IF YOU TAKE THE PROGRESS CHECK AND ANSWER ALL OF THE QUESTIONS CORRECTLY, YOU HAVE MASTERED THE MATERIAL AND ARE READY TO TAKE THE MODULE TEST. SEE YOUR LEARNING SUPERVISOR.

IF YOU DECIDE NOT TO TAKE THE PROGRESS CHECK AT THIS TIME, OR IF YOU MISSED ONE OR MORE QUESTIONS, STUDY ANY METHOD OF INSTRUCTION YOU WISH UNTIL YOU HAVE ANSWERED ALL THE PROGRESS CHECK QUESTIONS CORRECTLY. THEN SEE YOUR LEARNING SUPERVISOR AND ASK TO TAKE THE MODULE TEST.